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WADC TECHNICAL REPORT 55-234

FABRICATION AND TEST OF TITANIUM JET PODS

FRED C. HOWER
E. W. FEDDERSEN

CONVAIR
A DIVISION OF GENERAL DYNAMICS CORPORATION
(FORT WORTH)

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WRIGHT AIR DEVELOPMENT CENTER

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AIRCRAFT LABORATORY
CHANGE ORDER 105 TO CONTRACT NO. AF33(038)-2182
PROJECT NO. 1368

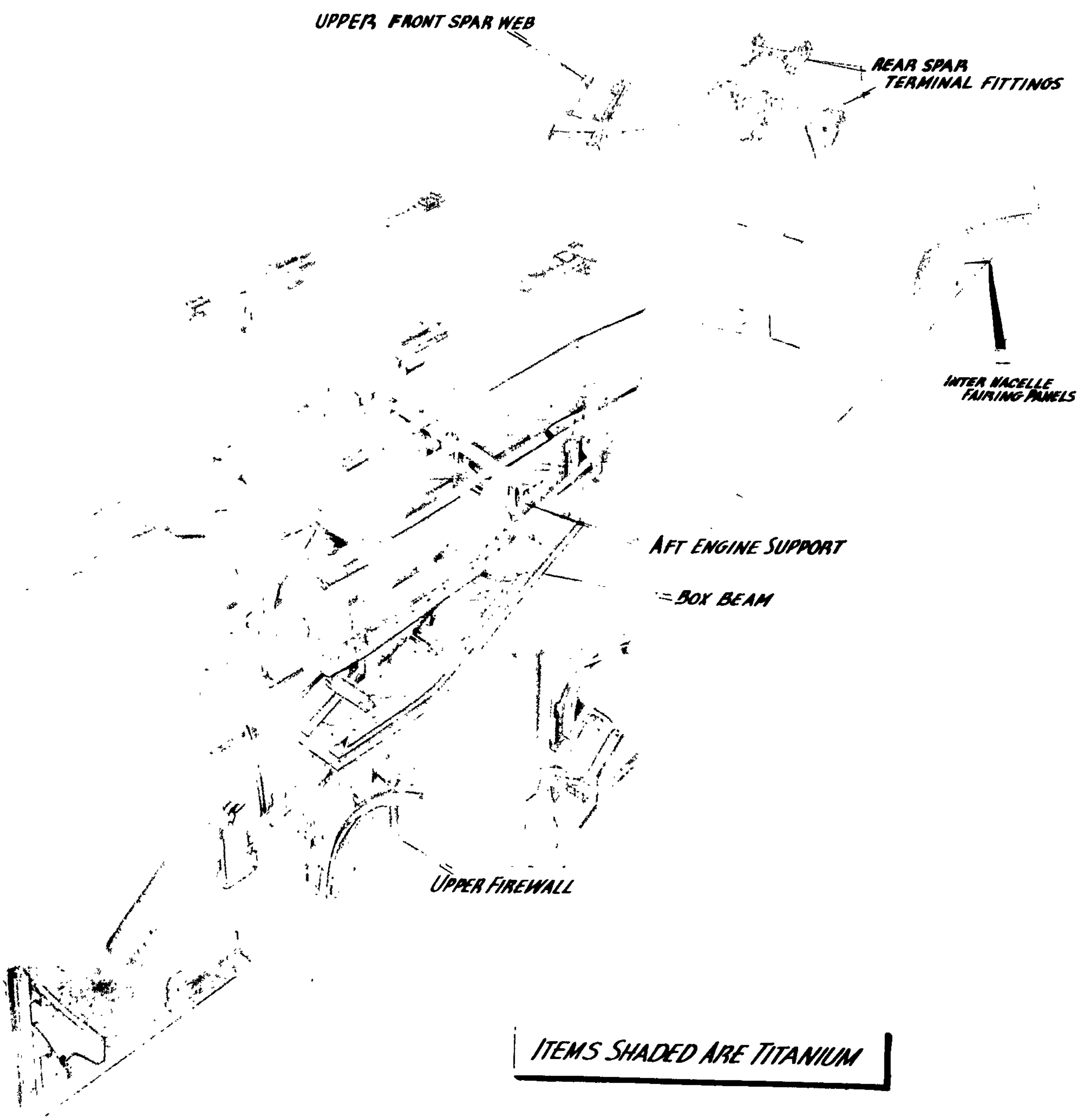
WRIGHT AIR DEVELOPMEHT CENTER
AIR RESEARCH AND DEVELOPMENT COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

FOREWORD

This is the final report of the "Fabrication and Test of Titanium Jet Pods" program. Work was accomplished at Convair, A Division of General Dynamics Corporation, Fort Worth, Texas, in fulfillment of Change Order 105 to Contract AF33(038)2182, and at Wright Air Development Center under Project Number 1368 entitled "Construction Techniques and Applications of New Materials".

The WADC Project Engineer was Fred C. Hower. The Convair-Fort Worth Project Engineer was E. W. Feddersen. Mr. Feddersen was assisted by C. F. Crabtree of Convair Engineering and W. O. Sunafrank of Convair Tooling. This report was edited by J. R. Conder of Convair Engineering.

TITANIUM J-47 POD



ABSTRACT

Titanium alloy was substituted for stainless steel in two J47 jet pods as flight test articles. Static test articles and jigs were submitted to WADC for laboratory evaluation.

The procurement of material and the inconsistent physical properties encountered are reviewed.

Basic recommendations are given for fabrication and tooling techniques required to form, machine or assemble titanium alloy parts. Where parts and tools were extremely difficult to make a detailed description of the steps taken is given. This description includes the failures as well as successful developments.

Firm design and fabrication limitations are not given in the report due to the inconsistent material which was available. However, improvement in both surface condition and physical properties was noted in the last material received.

Titanium alloy can be fabricated into airframe parts, but high production will be difficult until a consistent material is available.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

Hugh O. Lippman
for DANIEL D. McKEE
Colonel, USAF
Chief, Aircraft Laboratory

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SECTION 1

SUMMARY

SECTION I

SUMMARY

1.1 Intent of Program

By 1950, considerable information had been gathered concerning the use of titanium alloy. However, since the material was in its infancy of development, it was natural that many contradictory statements appeared. It seemed that many of these statements were made without sufficient qualification although the basic issues were generally in agreement.

The inherent properties of titanium, particularly the high strength-weight ratio of titanium alloys, combined with its obvious design advantages, emphasized the necessity for the rapid attainment of effective manufacturing methods, processes and techniques.

With these advantages in mind, Convair proposed a program which was intended to furnish first-hand information and actual shop fabrication experience on alloyed titanium material. In addition, parts made under this program were to be incorporated into an airframe as primary structural and nonstructural members and flight tested to determine their suitability and service life.

1.2 Scope of Program

This program was established for the development of titanium alloy as a replacement material for steel in the fabrication of various structural and nonstructural parts of the J47 jet engine pod on the B-36.

The program consisted of these two phases:

1. The first phase was concerned with the design and fabrication of static test articles for evaluation by the Wright Air Development Center.

2. The second phase consisted of the fabrication of redesigned jet pod parts and the installation of the parts in two B-36 jet engine pods. These pods were flight tested to establish data on the titanium alloy material, as compared with steel, in aircraft structures.

1.3 Results of the Program

The outcome of this program has proven that if basic techniques and procedures have been established for the material available, titanium alloy parts can be produced under closely controlled conditions and with specialized tooling. Convair Engineering and Tooling followed this line of thinking.

Due to the great variations in the available titanium alloy, definite design and fabrication limits could not, and still cannot, be established. Only when uniform material which met established specifications was available, could production procedures and parts fabrication techniques be established.

During the course of the titanium program at Convair, considerable improvement in the quality of material received from the vendor became evident by the end of the program. Uniformity of gauge, physical properties of a higher nature, and better workability were evident. Detail parts were made with a minimum of trouble. The same parts could not be made with material received at the start of the program. The titanium producers had clearly shown that they were improving the quality of their material.

A total of 310 detail parts were fabricated from sheet material for the flight test pods and 113 sheet metal details were fabricated for the static test program.

A total of 28 titanium alloy forgings of three different types were fabricated; eight for the flight test pods and 20 for the static test program.

A breakdown of the flight test pods is as follows:

Sheet metal details	-	91.69 lbs/nac.
Forgings		18.67 lbs/nac.
		110.36 lbs/nac.
		or
		220.72 lbs/airplane

The above 220.72 pounds of titanium alloy parts used in the two flight test pods resulted in a weight saving of 146.37 pounds in the flight test airplane.

The two flight test pods were installed on B-36 airplane No. 51 and 183 hours of flight time was accumulated during 33 flights. The jet engines were operated an average of 80 hours during this period.

Inspection of the titanium alloy parts at the completion of the tests found them to be still serviceable. (Reference Figures 1 and 2, pages 6 and 7).

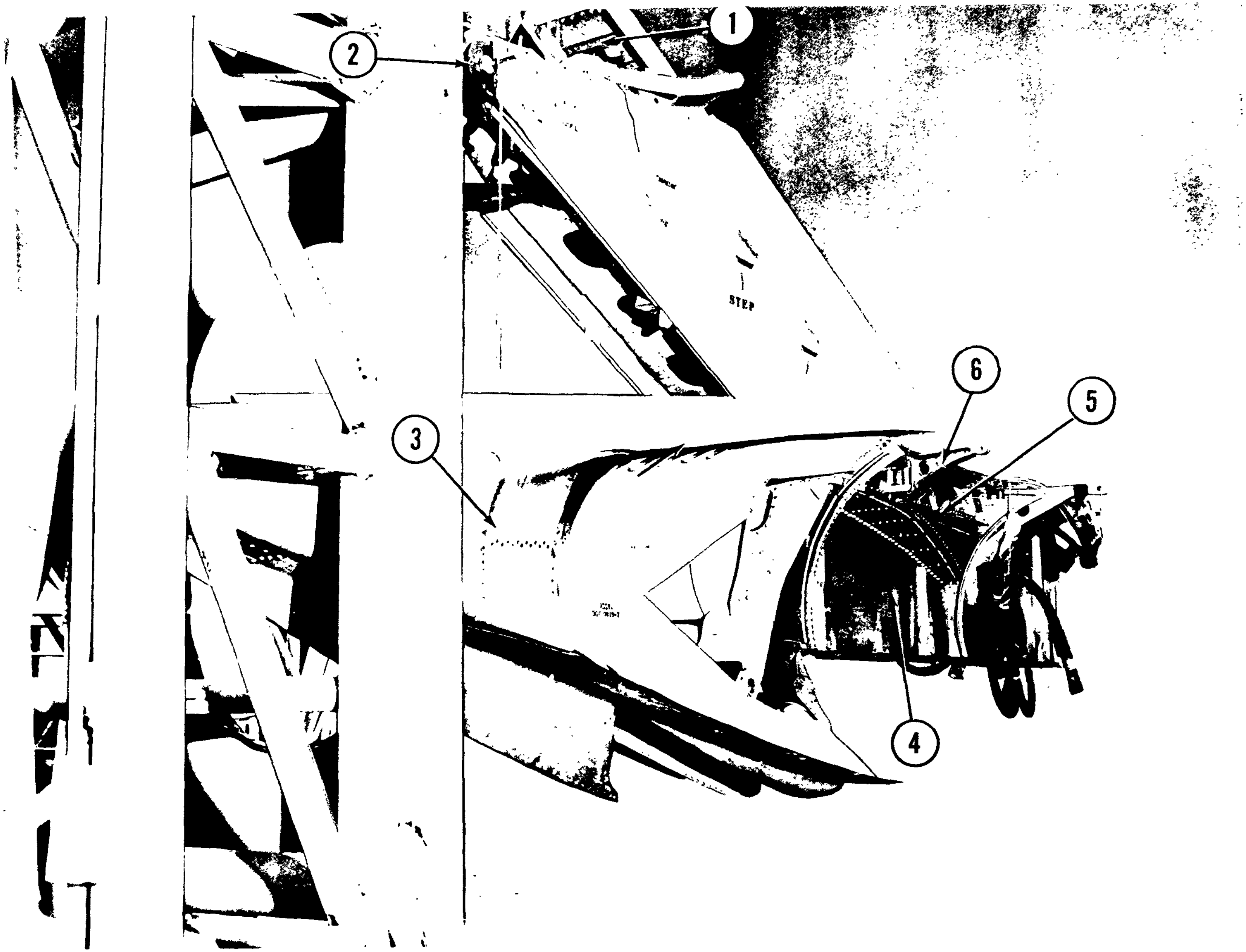


FIGURE 1

ABOVE IS SHOWN ONE OF THE TWO FLIGHT TEST PODS. THE ITEMS FABRICATED FROM TITANIUM ARE AS FOLLOWS: 1. FRONT SPAR WEB, 2. REAR SPAR TERMINAL FITTINGS, 3. INTER-NACELLE FAIRING SIDE PANELS, 4. UPPER FIREWALL, 5. BOX BEAM, AND, 6. REAR ENGINE SUPPORT FORGINGS.

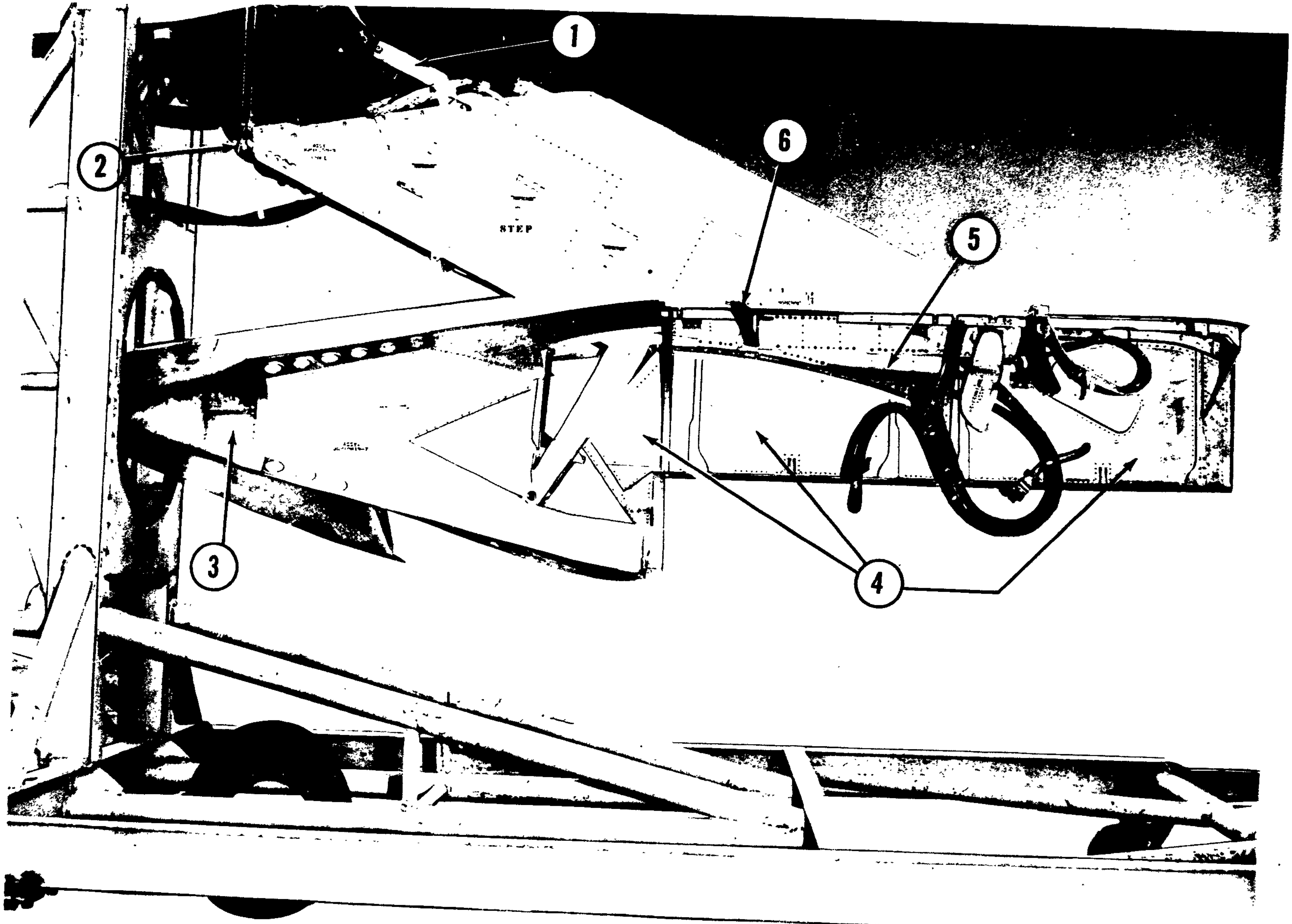


FIGURE 2

HERE IS ANOTHER VIEW OF A COMPLETED POD SHOWING MAJOR SECTIONS FABRICATED FROM TITANIUM ALLOY: 1. FRONT SPAR WEB, 2. REAR SPAR TERMINAL FITTINGS, 3. INTER-NACELLE FAIRING SIDE PANELS, 4. UPPER FIREWALL, 5. BOX BEAM, AND, 6. AFT-ENGINE SUPPORT FORGINGS.

MATERIAL

WADC TR 55-234

SECTION II

MATERIAL

2.1 Summary

For this program, all of the material used in the fabrication of the flight test pods and the static test articles was titanium alloy as listed below:

Sheet material - Republic Steel Corporation
RS-110 and RS-120

Forging stock - Titanium Metals Corporation - Ti-150A

Bar stock for static test bolts - Rem-Cru Titanium Inc.
Titanium Metals Corporation - RC-130B

Attempts were made to use Titanium Metals Corporation Ti-140A sheet material but the material received was not acceptable for fabrication.

Two forgings were made from Mallory-Sharon 3Al-5Cr titanium alloy forging stock but were not used although they were acceptable parts.

2.2 Discussion

2.2.1 Specifications

Since no specifications for titanium alloy material were available at the beginning of the program, a Convair procurement specification was prepared and used.

2.2.2 Requirements

The following is a list of titanium alloy material procured and used in this program:

Sheet stock

RS-120 material

4 sheets - .025 x 36 x 120

1 sheet - .035 x 36 x 60

4 sheets - .035 x 36 x 96

1 sheet - .035 x 36 x 120

4 sheets - .042 x 36 x 60

3 sheets - .042 x 36 x 96

5 sheets - .050 x 36 x 60

1 sheet - .050 x 36 x 72

3 sheets - .050 x 36 x 96

1 sheet - .063 x 36 x 36

1 sheet - .063 x 36 x 96

2 sheets - .093 x 36 x 60

1 sheet - .093 x 36 x 96

1 sheet - .375 x 36 x 36

RS-110 Material

1 sheet - .063 x 36 x 72

1 sheet - .093 x 24 x 60

1 sheet - .093 x 36 x 72

1 sheet - .093 x 36 x 84

1 sheet - .093 x 36 x 96

Forging Billets

Ti-150A titanium alloy

14 pieces - 2 3/8 dia. x 11

12 pieces - 4 3/4 round-cornered square x 10½

5 pieces - 3½ dia. x 9

14S aluminum

8 pieces 5 5/16 dia. x 10½

8 pieces - 2 3/8 dia. x 11

Titanium forging stock was specified to have the following physical properties:

Ultimate tensile strength (psi) - 150,000

Tensile yield strength (psi) - 145,000

Per Cent Elongation in 2 inches - 10

Aluminum forgings were made for the static test program so that a comparison of strengths and fatigue characteristics could be made.

2.2.3 Procurement

Following contractual approval of this program, representatives of Convair visited the facilities of Titanium

Metals Corporation, Rem-Cru Titanium Corporation, and Republic Steel Corporation to determine which of these organizations could best meet the established material specifications and delivery schedules.

As a result of this investigation, Republic Steel was chosen as the material source since their quoted delivery schedule was the only one compatible with on-time program completion. Purchase orders for titanium alloy sheets conforming to Convair's specifications were placed with Republic Steel in April 1952 for June 1952 delivery.

In accordance with Republic Steel's prior commitment, shipments were to start in the latter part of May 1952, with final shipment to be made in June 1952. A continuous follow-up was made with Republic Steel and prior to the first nation-wide steel strike in April 1952, Republic Steel advised that they would meet the June delivery. On 2 June 1952, the second steel strike was called and Republic Steel advised Convair that deliveries could not be made until after the strike. The strike ended on 26 July 1952, and Republic Steel advised Convair on 1 August 1952 that shipments would start around 15 August 1952. They further advised that complete delivery could be made in the latter part of that month. However, only small quantities of material were received intermittently between 15 August and 1 December 1952.

In mid-December 1952, Convair was advised that some of the heavier gauges were ready for shipment and Republic Steel affirmed early delivery for the balance of the order.

On 22 December 1952, Republic Steel advised Convair that since they were experiencing further rolling difficulties they could give no definite delivery date for the balance of the material and that Convair's orders would be held on an indefinite basis.

Republic Steel airmailed to Convair a sample sheet of titanium alloy which was representative of the peculiar surface condition encountered in rolling light gauge sheets of .050 inch and under. This sample was processed to determine its suitability for use. The results of these tests indicated that the properties and surface condition of this material were unacceptable.

As a result of the material procurement problems outlined above, Convair sought to obtain the necessary material from Rem-Cru Titanium Corporation. This alternate source was chosen because its titanium alloy is a manganese alloy similar to that produced by Republic Steel. Rem-Cru quoted a seven-month delivery schedule for the required material.

APRA was contacted by Convair and requested to aid in reducing the delivery schedule quoted by Rem-Cru. This organization was unable to effect a better delivery schedule.

A representative of Convair visited the facilities of Titanium Metals Corporation, Rem-Cru Titanium Corporation, and Republic Steel Corporation, in a further attempt to procure the required material.

It was learned that Titanium Metals Corporation could supply the necessary material from a billet on hand having physical properties which met Convair's specifications. Orders were placed for the remaining material needed and was scheduled for delivery in February 1953; however, Titanium Metals Corporation notified Convair that they were unable to roll alloy material under .047 inch thickness. It was also stated that Convair's order had been rolled four times without success and that the delivery date would be indefinite.

In early February 1953, Republic Steel solved their rolling problems and Convair received the remaining material needed except for some .063 and .093 gauge sheets. The material received possessed good physical properties except for poor surface flatness. Eleven of the seventeen sheets received were rejected because of this condition; however, as replacement material was not available and as the completion of this program was essential, the material was accepted and released for use on 26 February 1953. (Reference Figure 3 page 17)

In March 1953 Convair was advised by Titanium Metals Corporation that a portion of the material ordered would be shipped in April 1953. This material was received but from it acceptable parts could not be fabricated so the material was returned to Titanium Metals Corporation and the remaining orders were cancelled.

To complete the fabrication of all detail parts, .063 and .093 gauge material was still needed. Minimum quoted delivery for this material was 45 days and per past performance of vendors, there was no reason to believe that quoted delivery schedules would be met or that required quality would be obtained. In May 1953, Convair submitted

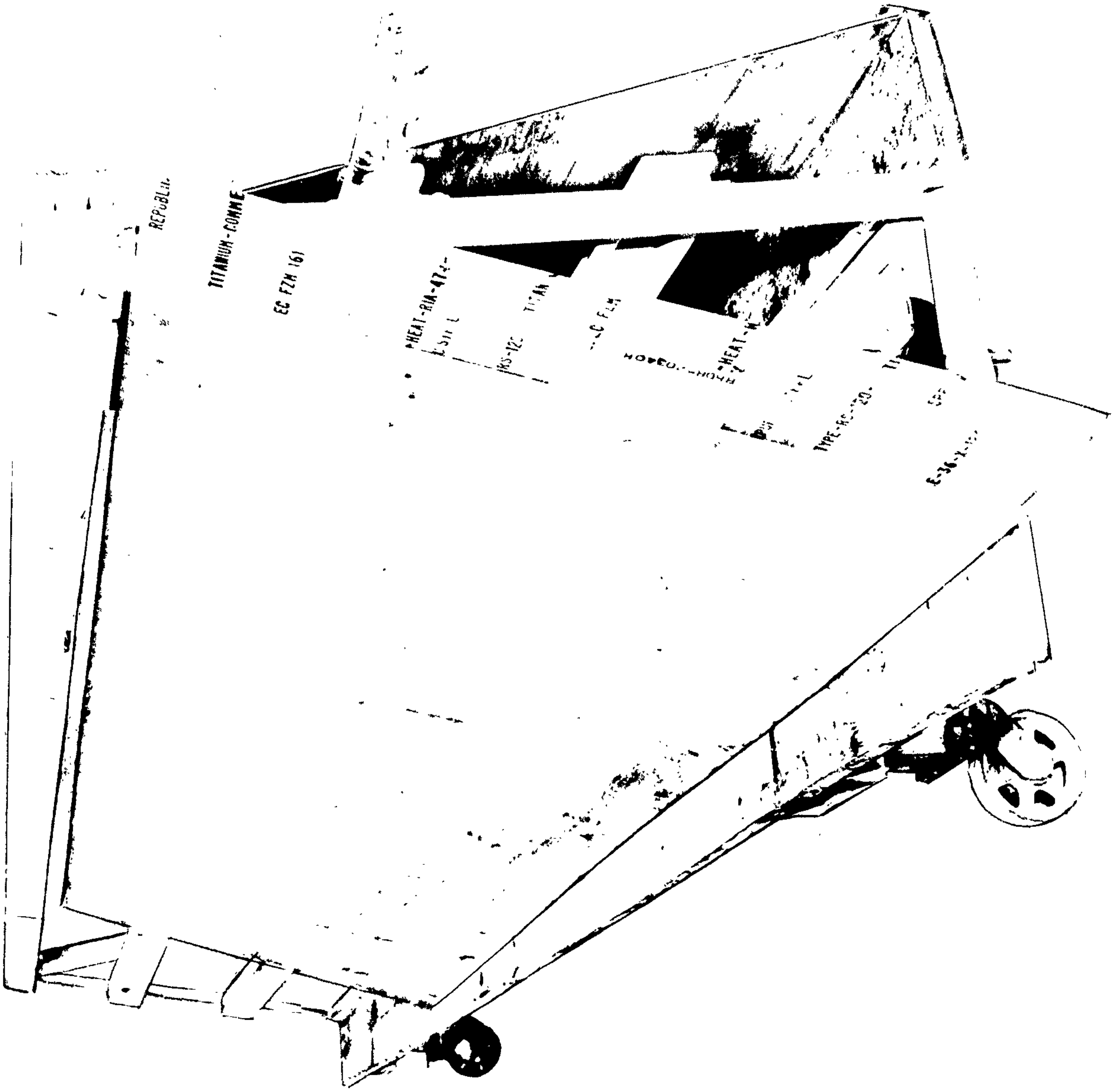


FIGURE 3
TYPICAL CONDITION ENCOUNTERED IN LIGHT GAGE SHEETS OF RS-120 TITANIUM.

a request to AMC for authorization to substitute stainless steel for titanium alloy on the remaining eleven detail parts.

In October 1953, Convair was advised by AMC that Republic Steel Corporation could immediately supply the needed material. Orders were then placed for RS-110 titanium alloy to meet AMS specification No. 4908. This material was received in November 1953 and test results showed that this material was of better quality than any received during the entire program.

The remaining detail parts were successfully fabricated and the two flight test pods were completed in February 1954.

2.2.4 <u>Receiving and Inspection Procedures</u>

On receipt of a crated shipment of titanium alloy, each lug or crate was thoroughly checked against the shipping receipt for quantities, gauges, vendor heat identification, and sheet sizes. After the lug was opened, the packing list was compared with the shipping receipt and any variation between the shipping and packing receipts was noted.

2.2.4.1 Inspection Procedures

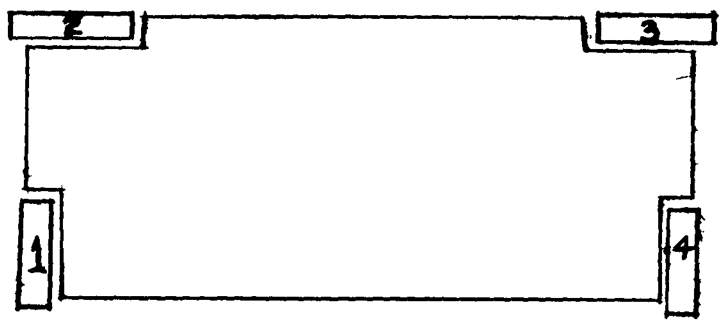
Inspection of titanium alloy material required the identification of each individual sheet bar, or forging, with the shipping and/or packing list. A visual inspection was made for laminations, gauge, laps, inclusions and general condition. Gauge variations between vendor markings and actual micrometer readings were recorded on a material control sheet. Each vendor's heat identification was noted and each sheet and plate was given an identifying number.

For test purposes, coupons were then removed from the new material and forwarded to Process Control for evaluation. The results of all tests were recorded on the material control sheet. This system provided a complete record of gauge variations, hardness, yield and tensile strengths, elongation at designated points, and minimum allowable bend radii by which material was designated to specific detail parts.

2.2.5 Acceptance Tests

Variances in the mechanical and physical properties of the titanium alloy received at Convair, forced the inauguration of a program of material acceptance testing prior to material release for tooling and fabrication.

All sheets of titanium received were checked to acceptance test procedures as outlined below:



The above sketch represents a typical material sheet and illustrates the type of samples and how they were taken for acceptance testing. These samples were subdivided into specimens of various sizes which were then allocated for and subjected to the following tests:

1. 105-degree bend at 550°F over a radius of 3 x thickness - Transverse and longitudinal tests were made of all four corners of the specimen.
2. 105-degree bend at 550°F over a radius of 2 x thickness - Transverse and longitudinal tests were made of all four corners of the specimen.
3. A chemical analysis was made of all four corners.

4. Tensile stress analysis (transverse) - Pull coupon taken from corner No. 1.
5. Tensile stress analysis (longitudinal) - Pull coupon taken from corner No. 2.

Several conclusions can be drawn from the results of the acceptance tests: (Reference Table II, page 23)

1. The spread between tensile ultimate and yield strengths is no indication of the elongation value.
2. The spread between tensile ultimate and yield strengths is not necessarily an index of the material's forming qualities.
3. Elongation is not connotative of the formability.
4. There was no correlation between the hardness and the strength of the specimens. (Reference Figure 4, page 24)

The following table shows typical properties of the titanium alloy material received at Convair at the start of the program compared with the material received by the end of the program. It can be seen that the material received last showed properties considerably more uniform than those materials acquired at the beginning. (Reference Table I, page 22)

TABLE I

MATERIAL EVALUATION

Date Mat'l. Received	Oct. 1952	Oct. 1952	Oct. 1952	Dec. 1953	Dec. 1953	Dec. '53
Mat'l. Type	RS-120	RS-120	RS-120	RS-110	RS-110	RS-110
Sheet Gauge (In.)	.093	.063	.093	.093	.093	.063
%Manganese	5.38	4.93	6.40	6.20	6.35	6.10
Tensile Yield Strength - psi						
Transverse	116,000	128,900	109,800	128,000	133,000	139,900
Longitudinal	112,000	108,200	112,500	124,000	126,800	130,000
Ultimate Tensile Strength - psi						
Transverse	127,000	134,800	133,300	141,100	136,000	144,500
Longitudinal	142,000	128,000	135,120	138,500	139,900	142,000
Elongation % in 2 Inches						
Transverse	14	7	16	16	16	14
Longitudinal	4	14	14	18	16	16
3T Bend Radius at 550°F						
Transverse	Fair	Good	Fair	Good	Good	Good
Longitudinal	Good	Good	Poor	Good	Good	Good

TABLE II

TYPICAL RS-120 TITANIUM ALLOY

SHEET GAGE (INCHES)	HEAT NO.	CHEMICAL COMPOSITION			TENSILE YIELD STRENGTH - PSI		ULTIMATE TENSILE STRENGTH PSI		ELONGATION % IN 2 INCHES		3T BEND RADIUS AT 550°F		2T BEND RADIUS AT 550°F	
		%C	%Mn	%Ti	TRANSVERSE	LONGITUDINAL	TRANSVERSE	LONGITUDINAL	TRANSVERSE	LONGITUDINAL	TRANSVERSE	LONGITUDINAL	TRANSVERSE	LONGITUDINAL
.093	RIA-328	0.040	5.38	94.58	116,000	112,000	127,000	142,000	14	4	FAIR	GOOD	POOR	FAIR
.093	RIA-328	0.10	6.40	93.5	109,800	112,500	133,300	135,120	16	14	FAIR	POOR	POOR	POOR*
.050	RIA-349	-	-	-	130,000	129,000	134,000	139,000	10.5	18	GOOD	GOOD	POOR	FAIR
.050	RIA-349	0.040	5.38	93.58	128,820	122,146	133,250	138,960	9	14	FAIR	GOOD	POOR	GOOD
.063	RIA-350	0.040	4.93	95.03	128,900	108,200	134,800	128,000	7	14	GOOD	GOOD	FAIR	FAIR
.042	RIA-357	0.076	5.53	94.394	127,000	129,000	150,000	139,100	13	15	GOOD	GOOD	FAIR	GOOD
.042	RIA-357	0.072	5.43	94.498	144,300	127,600	149,500	140,000	15	17	GOOD	GOOD	GOOD	GOOD

*THIS SHEET OF MATERIAL REJECTED TO VENDOR

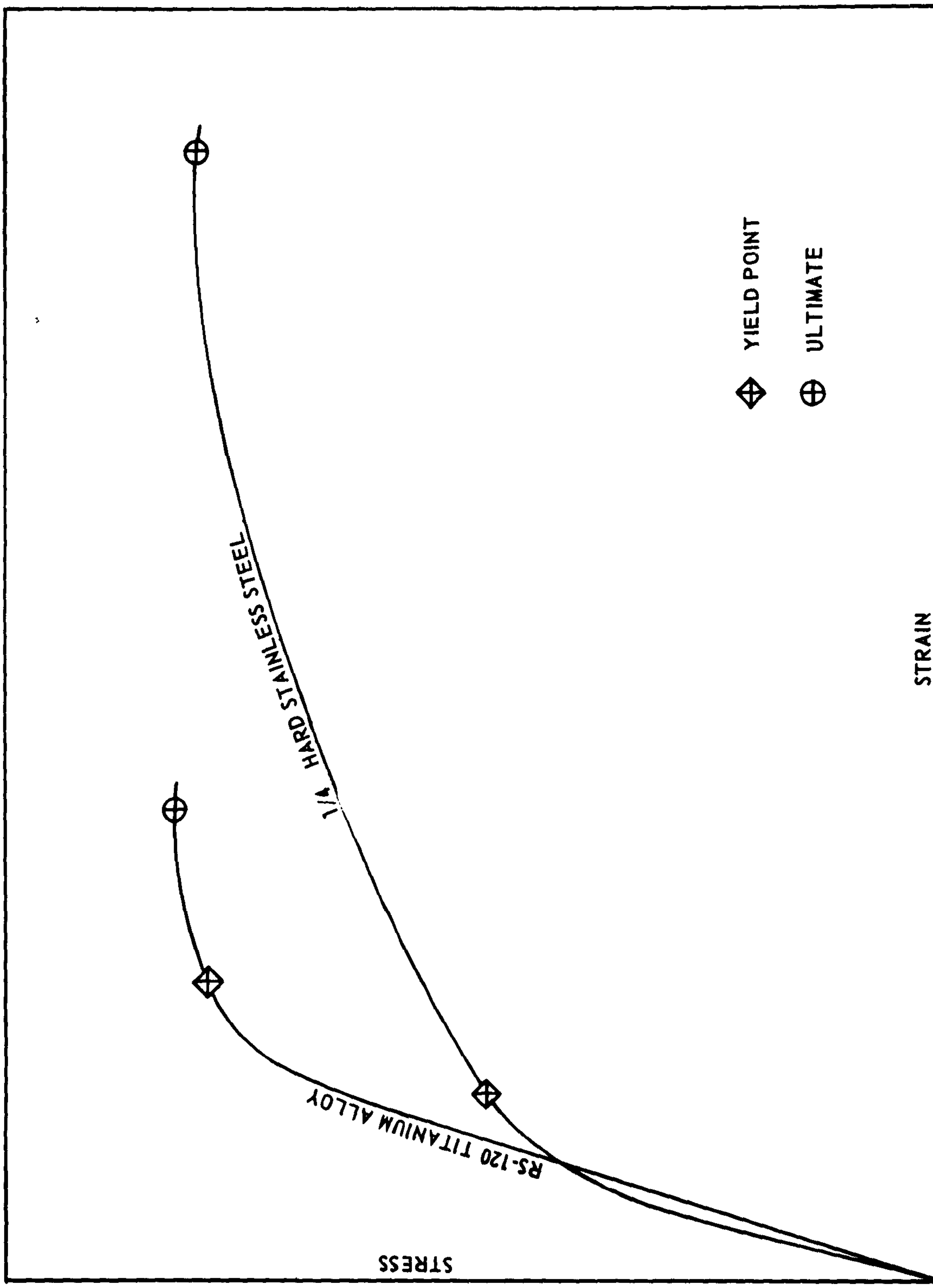


FIGURE 4

COMPARISON OF TYPICAL STRESS-STRAIN CURVES FOR TITANIUM ALLOY AND 1/4-HARD STAINLESS STEEL.

2.3 Recommendations on Material Procurement

The variances in mechanical and physical properties in titanium alloy material necessitates a program of material testing prior to acceptance and use. Each sheet should be evaluated as to forming characteristics and stocked according to an established class. Production parts should then be released against a specific class of material so that the best material will be available for severe fabrication. Such a program is deemed mandatory until the material producer is able to consistently produce material to established specifications.

SEC

PARTS FABRICATION

SECTION III

PARTS FABRICATION

3.1 Introduction

The use of titanium alloy for parts fabrication presented many new and complex problems. The slow rate of elongation, the resistance to bending, and compression in sheet stock, posed problems which required considerable tool development.

New tools using various means of heating were tried. Hydropress, draw press, drop hammer, and stretch forming were methods used with variable degrees of success. Due to the wide variations in material quality between each sheet and even within different areas of the same sheet, it was extremely difficult to set out specific processes and limitations. It is Convair's belief that basic procedures have been established.

Thin machining forgings and bar stock, cutter angles and cutting lubricants became very critical. Cutter life presented the primary problem due to high heat generated and the tendency of the material to cold weld to the tool.

3.2 Sheet Metal Fabrication

When a parts production order was released to the shop, all parts calling for the same gauge were reviewed. Those parts requiring severe forming were nested on the available sheet having good forming characteristics. Those parts requiring little or no forming were nested on sheets showing low formability. The forming qualities were determined from laboratory test reports.

The size blank required for each part was determined by using 1/4-hard stainless steel. By following the noted procedure and outlining each part on the suitable and available material, little waste from cutoffs was realized.

3.2.1 Shearing

Using regular production equipment, shear operations on gauges of .050 and over caused the material to separate into laminations or layers parallel to the material surface. These cracks penetrated approximately .06-inch deep and were apparent in all sheared sheet of the noted gauges.

In order to control this effect, is was necessary to band saw the blanks and parts to size. In the case of a straight-edged part that required stretch forming, excess material was allowed on the blank and the edge was then milled to the required dimensions. While this method was acceptable on a limited program it would not be adaptable to high or full scale production. (Reference Figure 5 page 30)

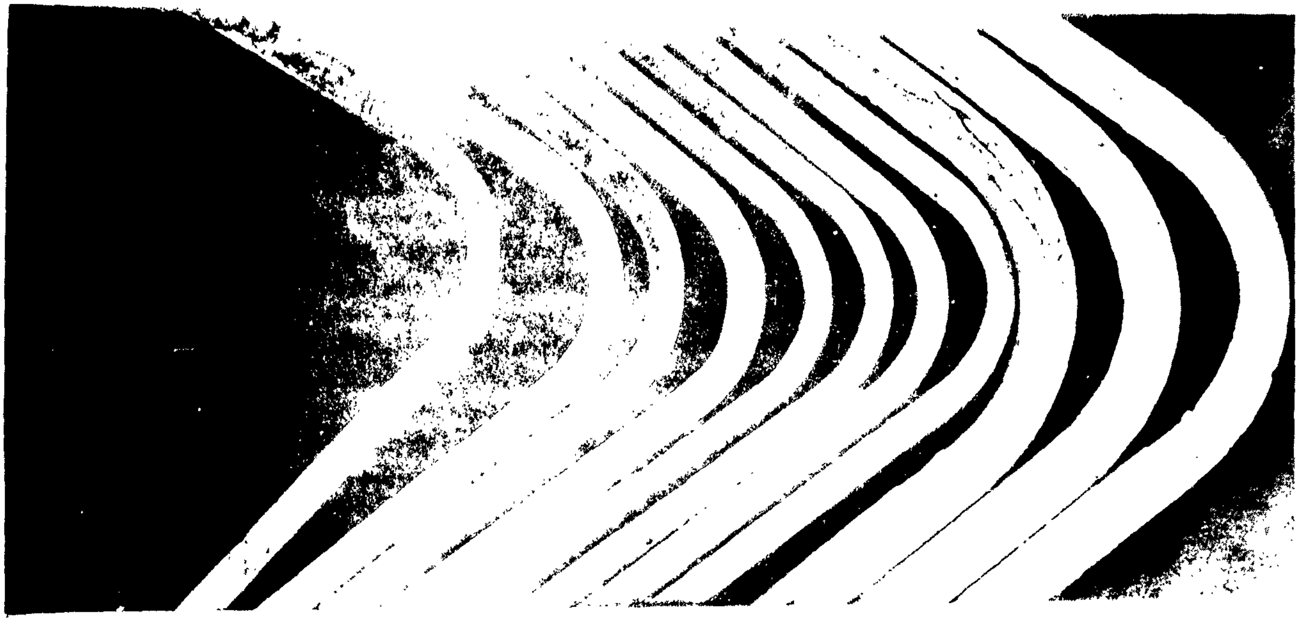
3.2.1.1 Recommendations

In view of parallel cracking, it is recommended that gauges of .050 and over be sawed to the required part outline or blank size.

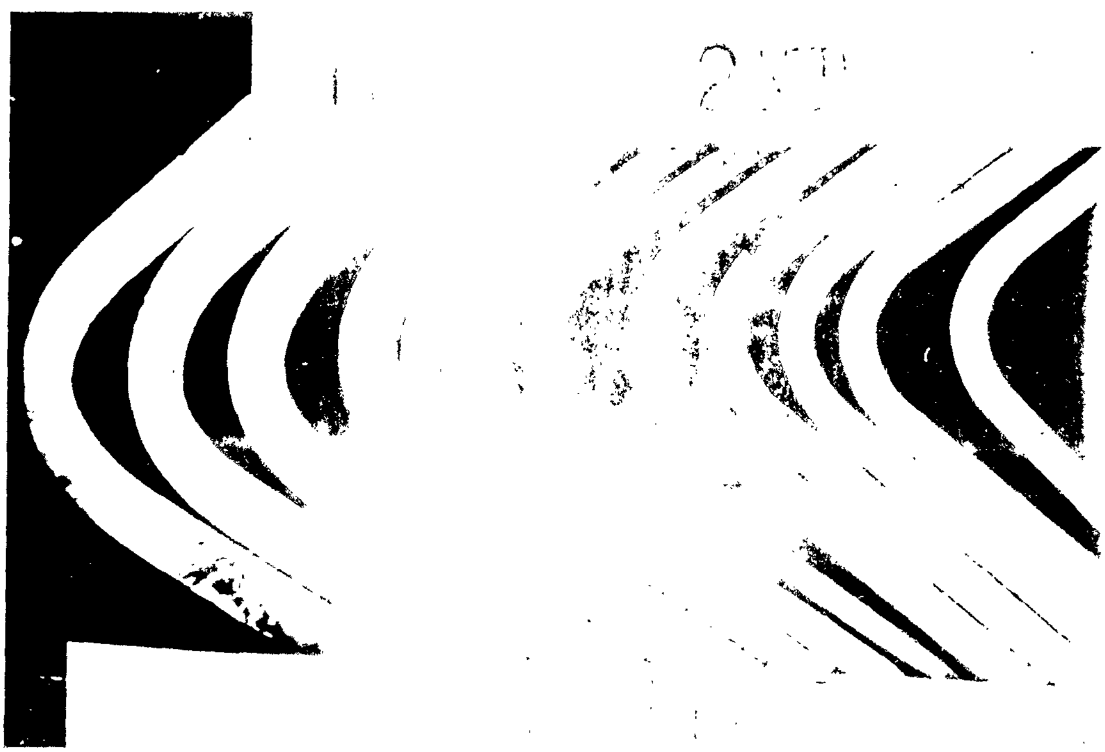
Blanks can be sheared provided the ruptured edge is machined after shearing to remove the laminated section. Blank and pierce operations should be limited to material of .050 thickness or under.

3.2.1.2 Discussion

Changes in shear clearance setting gave no improvement. It is hoped that research and improvement in future titanium alloy production will eliminate this tendency toward laminations. The last material received showed definite improvement and sheared satisfactorily when heated to 500°F. It is concluded that the resistance



EDGE VIEW OF BEND SPEC[illegible] SHOWING [illegible] CKS DUE TO SHEER OPERATIONS OF COUPONS BEF[illegible]



SAME COUPONS AS [illegible] MACHINING 1/16-INCH OFF THE EDGES.

to shearing and the brittleness within the available material was the chief cause of the laminar separations.

3.2.2 Nibbling

Since nibbling is a form of shear operation, the same laminating tendency can be expected as in shearing. Heavy equipment is required. Nibbling offers a reasonable approach for roughing out irregular shaped blanks for forming and subsequent trim operations. In this way the laminated edge will be removed from the finished part.

3.2.2.1 Recommendations

Nibbling operations on gauges above .050 should be confined to roughing out blanks and rough-formed parts which will be sawed or milled at a later stage of fabrication to final dimensions in order to remove any laminated or separated areas.

Nibbling is a satisfactory operation on gauges under .050. Only sturdy rigid equipment should be used due to the high resistance to shearing offered by titanium alloys.

3.2.3 Routing

The high rpm of routing equipment and the high heat generated resulted in extremely short cutter life. Routing operations were not practical on titanium alloys.

3.2.4 Sawing

Both high-speed and low-speed hand sawing were investigated for sawing titanium alloy.

3.2.4.1 Recommendations

Metalloid, and cutting oil were used with the various types of saws but no improvement was noted. The table below shows the results in saw blade life using different blades, speeds, and feeds on .375-thick titanium alloy plate.

BAND SAW LIFE RELATIVE TO CUTTING AND FEEDING SPEEDS

DOALL BAND SAW Saw Type	SURFACE FEET Per Minute	FEED AT START In. Per Min.	SAW LIFE Per In. of Cut
1/2-inch 4 teeth per in.	85	1/2	2
1/2-inch 14 teeth per in.	100	1	3
1/2-inch 14 teeth per in.	85	1-1/4	4
1/2-inch 14 teeth per in.	60	1/2	3
1/2-inch 10 teeth per in.	60	1	11
1/2-inch 14 teeth per in.	60	1-1/4	30

In high-speed sawing, a one-inch, 14 teeth-per-inch saw was tried at 11,309 surface-feet-per-minute. This method gave unsatisfactory results; the material reached a red heat and feeding was slow. The same type saw was then tried in reverse with similarly poor results.

A one-inch, skip-tooth, 4 feet-per-inch saw, running in reverse at 11,309 surface-feet-per-minute, gave excellent results; .375 material was fed into the saw at approximately 12 inches-per-minute and produced a good smooth cut. Heat generated was low and the hardened surface produced was not over .002-inch thick. No difficulty was experienced in removing this hardened surface.

3.2.4.2 Discussion

The high-speed sawing of titanium alloy created a thin, hardened surface as noted. This surface when magnified showed fine hairline surface cracks apparently due to rapid cooling of the material. It was imperative that this surface be removed from the finished part to eliminate the possibility of further cracking under stress. This can be best accomplished by subsequent machining operations as is done on lighter gauges through filing.

Slow-speed sawing can be successfully used for heavy gauge sheet, plate stock and forgings, however, saw life is short. Feeds should be heavy to preclude the possibility of slippage and the resulting reduction of blade life.

There is a fire hazard; inflammable materials such as magnesium dust must be removed from the area before sawing titanium.

3.2.5 Abrasive Cutoff

Abrasive cutoff operations did not prove satisfactory. Test operations on both bar stock and plate indicated that the high heat generated and the resulting hardened surface were detrimental to the cutoff operation and subsequent machine operations.

3.2.5.1 Discussion

Abrasive cutoff created a burned-hardened surface approximately .06 deep. This surface was crisscrossed with fine hairline cracks which had a tendency to spread. This surface was extremely hard and was difficult to remove. A Rockwell test for surface hardness showed an average reading of 54C. Cutoff time is slow and wear on the abrasive wheel is excessive.

3.2.6 Punch and Draw Press Operations

Normal steel form and draw dies were not satisfactory for titanium alloy material. Major problems were:

(1) Excessive springback, even at elevated temperatures

(2) Resistance to compression

(3) Galling tendencies

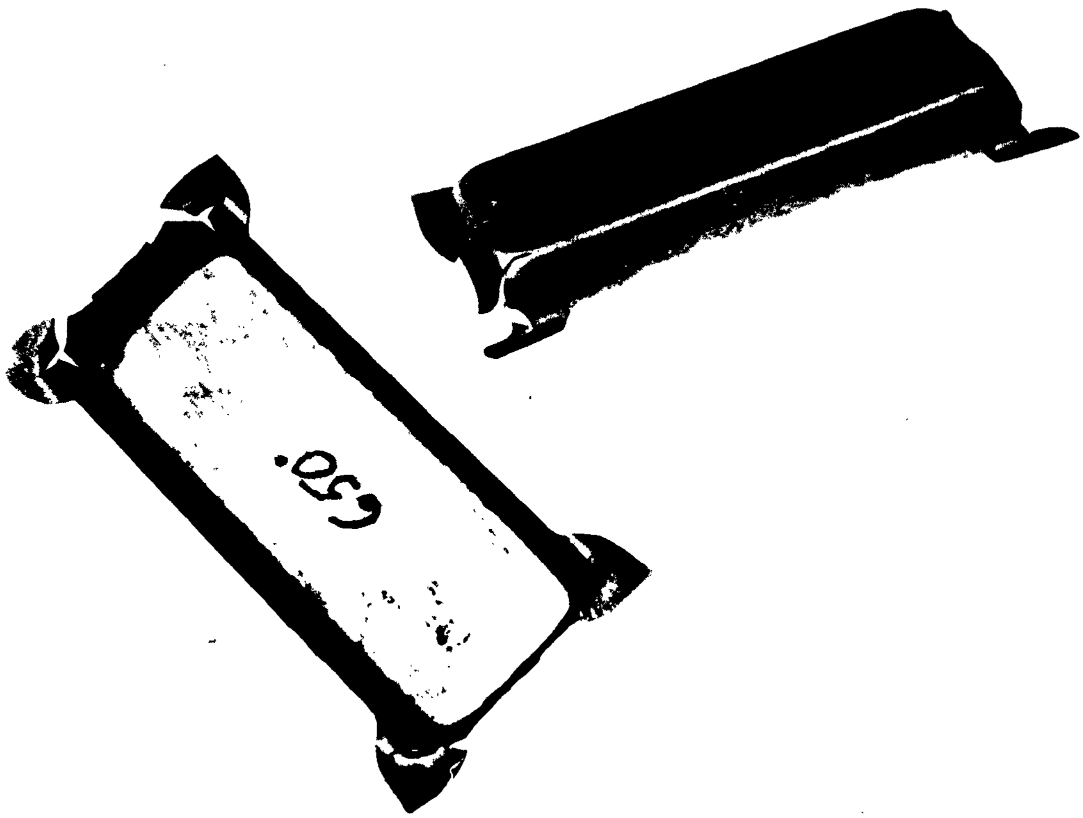
(4) Lubricant breakdown at elevated temperatures

3.2.6.1 Forming and Drawing

Both mechanical punch press and hydraulic draw press operations were used. Temperatures up to 1000°F were tried. It was found that titanium alloy was more difficult to draw than 1/2-hard stainless steel. Secondary sizing operations, and extensive hand work at temperatures of 500°-600°F were required.

Straight-sided parts formed on steel form and draw dies have curled side walls. Hand working at 500°-600°F is required to remove this curl to a degree to make the parts acceptable. Springback, compression bows and canned areas were problems which must be considered in parts design. (Reference Figure 6, page 36)

Consideration must be given these limitations and accept them, or provide a method of eliminating them;



THE DRAWN BOXES SHOWN ABOVE WERE ATTEMPTED USING .032 GAUGE RS-120 TITANIUM ALLOY. IN AN EFFORT TO OBTAIN COMPARATIVE DEEP DRAW DATA, THESE PARTS WERE RUN ON A HOT DIE USED FOR PRODUCTION OF MAGNESIUM PARTS. TEMPERATURES OF 550°F FOR THE UPPER PART AND 650°F FOR THE LOWER PART WERE USED WITH GRAPHITE LUBRICANT. THE FOLLOWING POINTS SHOULD BE NOTED:

1. STRAIGHT SIDE WALL SECTIONS RETAIN THE CURL IN PASSING OVER A DRAW RADII.

2. THE TYPE FRACTURES INDICATED IN THE UPPER PART APPEARED THREE MINUTES AFTER COMPLETION OF DRAW. FURTHER CRACKS RADIATED FROM THE ORIGINAL FRACTURE.

   A. DOUBLE FRACTURES FOLLOWING GRAIN DIRECTION APPEARED IN THE COMPRESSION CORNERS. NORMAL FRACTURES EXPECTED WOULD HAVE BEEN ACROSS THE CORNERS RESULTING FROM EXCESSIVE TENSION.

   B. FRACTURES OCCURRED IN THE STRAIGHT SIDE WALL AREAS AS SHOWN IN THE END SECTION OF THE LOWER PART.

FIGURE 6

such as a bead pattern in the bottom of pans to remove the canned area and relief scallops to remove strain in compression flanges.

In a limited program such as was undertaken in the fabrication of the two jet pod assemblies at Convair, considerable hand work was utilized in straightening and completing the forming of parts. This, however, would not be acceptable on an extensive production program.

Proper lubrication, at the elevated temperatures used, was only partially solved. Molybdenum disulfide powder, both dry and mixed to a thick paste with Dow-Corning silicone grease, gave best results in reducing the galling tendencies of drawn parts.

Heated dies should be made of cast iron and the draw surfaces chrome plated.

3.2.6.2 Blanking and Piercing

As was noted in shearing operations, blanking and piercing operations also were limited to the lighter gauges of titanium alloys due to laminated material.

The use of heavy duty dies and equipment was mandatory to blank titanium alloys. While blanking and piercing operations were very limited on the jet pod project, sufficient information was gained to establish that tool damage by these operations is considerable. Positive striping was essential. Clearances should be about the same as for mild steel. In sufficient clearances cause galling on the punch and therefore caused short life.

3.2.7 Hydropress Forming

Hydropress forming and Hi-Draw forming gave fairly successful results with parts normally fabricated by this procedure. It was necessary to develop springback for hydropress form blocks for each individual part as it was impossible to establish a consistent pattern of springback variations in the material. This fact contributed heavily to this problem.

In Hi-Draw forming, the tendency of the side flanges to retain the curl created when passing over a draw radii, was similar to hydraulic draw press operations.

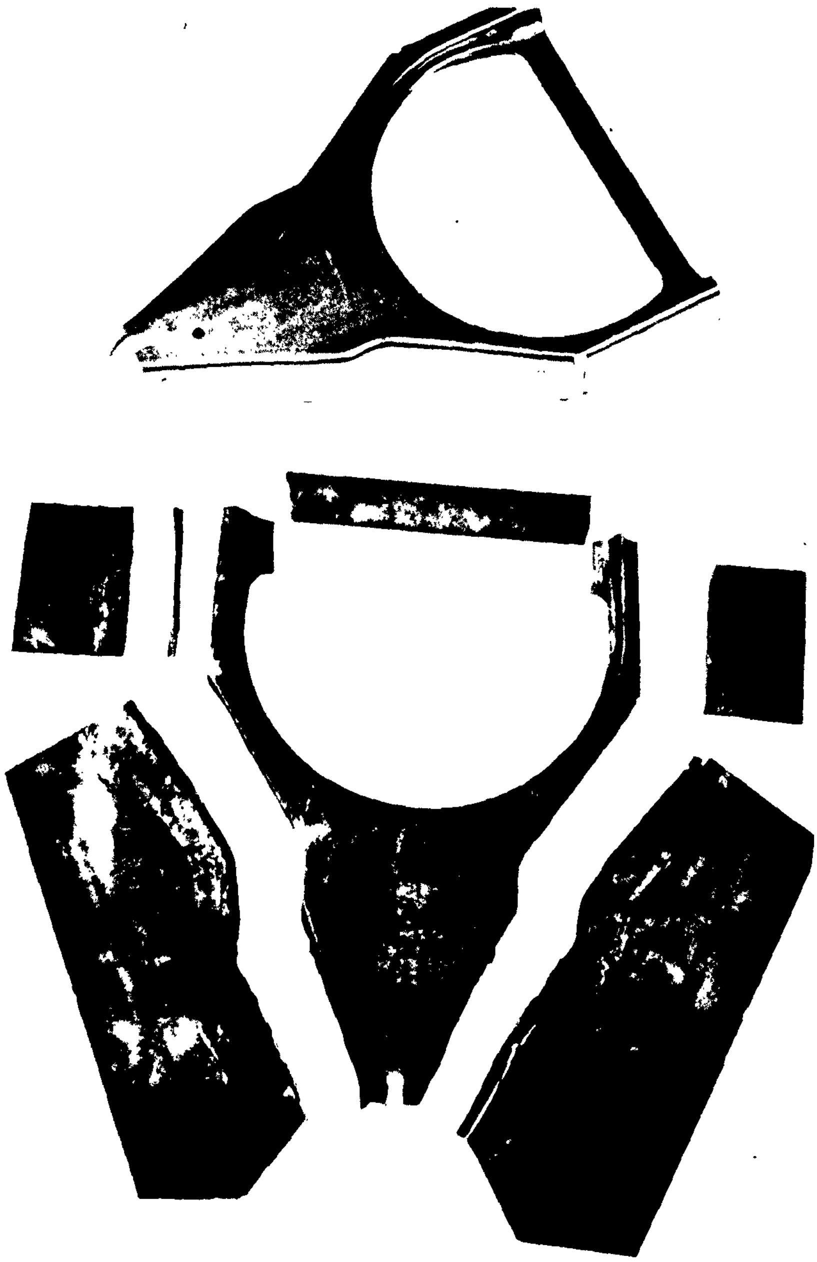
Radii of 4T-to-6T were necessary for hydropressing and Hi-Draw operations.

Temperatures of both 900°F and 550°F were tried. The high temperature improved forming but only a slight improvement resulted from the 900°F compared to the 550°F. On the basis of these tests, all hydropress operations were run at 550°F. Heat resisting rubber pads or blankets for the high temperatures were not good. Rubber life at the elevated temperatures was short in comparison to normal cold forming rubber life. (Reference Figures 7 and 8 , pages 40 and 41)

Good, clean joggles could not be formed by hydropress operation. Such joggles required development before satisfactory results could be obtained. Steel sizing die operations following hydropress forming gave best results. Scallops or reliefs were required in compression areas. These considerations should be designed into the parts. (Reference Figures 9 and 10 pages 42 and 43)

3.2.8 Brake Forming

Numerous brake bend tests, both hot and cold, were made in an attempt to establish definite bend radii. The wide variation in material quality, the low percentage of elongation, and grainy surface finish, all tended to give inconsistent results.



THE YOKE SHOWN IN THIS PHOTO REPRESENTS A HIDRAW OPERATION AT 900°F TEMPERATURE. THE MANNER IN WHICH THE BLANK SHATTERED REFLECTS THE BRITTLE NATURE OF THIS MATERIAL. THE MATERIAL USED IN THIS TEST WAS KNOWN TO POSSESS BRITTLE CHARACTERISTICS AS A RESULT OF THE MATERIAL ANALYSIS PROGRAM, AND THE RESULTS OBTAINED CLEARLY INDICATE THE FUTURE VALUE OF THIS PROGRAM. REJECTION OF MATERIAL SHOWING CHARACTERISTICS UNSUITABLE FOR SEVERE FORMING OPERATIONS WILL SUBSTANTIALLY REDUCE THE FREQUENCY OF PART FAILURES DURING PARTS FABRICATION.

FIGURE 7

FIGURE 8

ANOTHER HYDROPRESS OPERATION IS SHOWN ABOVE. THIS YOKE WAS ATTEMPTED AT 6,000 PSI. RESISTANCE TO DEFORMATION IS GREAT AND IS CLEARLY SHOWN BY COMPARISON OF THE MAGNESIUM PART "A" TO THE TITANIUM PARTS "B" AND "C". THE CRACKS IN PART "B" ARE THE RESULT OF RESIDUAL STRESS AND CONTINUED TO SPREAD THROUGH A 48 HOUR PERIOD. THESE OPERATIONS WERE PERFORMED AT TEMPERATURES OF 900° to 1000°F.

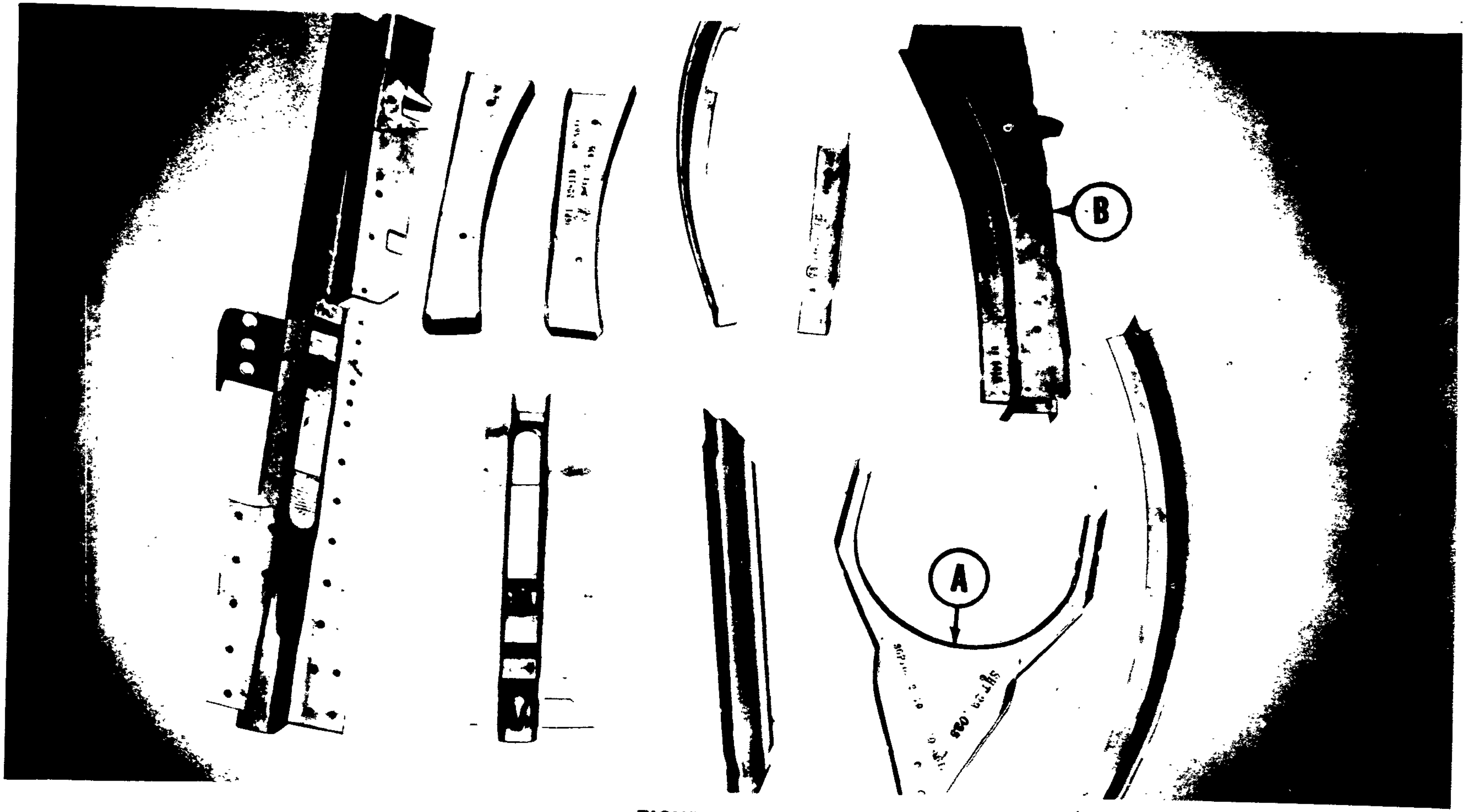
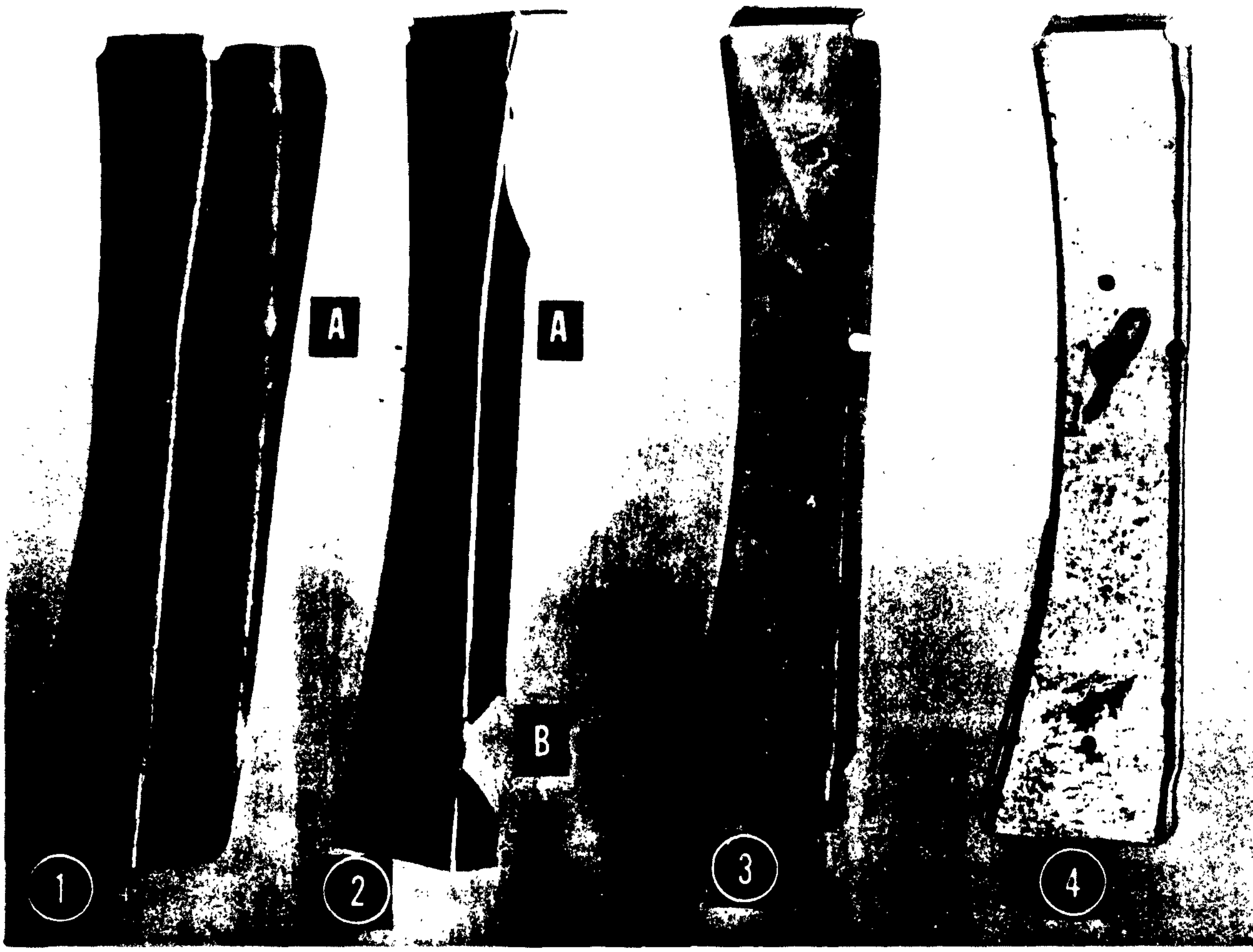


FIGURE 9

THIS SHOWS ALLOY TITANIUM DETAILS AND ASSEMBLIES REPRESENTING A GOOD CROSS SECTION OF FABRICATION TOOLING. THESE INCLUDE BRAKE FORMING, SPECIAL JOGGLE DIES, STANDARD JOGGLE SHIMS, HYDROPRESS BLOCKS, HUFFORD-TYPE STRETCH FORMING, AND STEEL FORM DIES. ALL OPERATIONS WERE PERFORMED AT 550-600°F WITH STRESS RELIEVING FOLLOWING EACH STEP OF FABRICATION.

THE YOKE WAS ONE OF THE PRELIMINARY DETAILS CHOSEN FOR TOOL DEVELOPMENT. THE FIRST APPROACH WAS A BASIC HYDROPRESS BLOCK AND THEN PROGRESSIVELY THROUGH PRE-FORM HYDROPRESS STAGES AND HIDRAW TOOLS WITHOUT SUCCESS. A GOOD PART WAS OBTAINED USING A STEEL FORM DIE WITH A HYDROPRESS SIZING OPERATION AT 6.000 PSI.

THE SCALLOPS WERE REQUIRED ON THE COMPRESSION FLANGE IN ORDER TO OBTAIN A FLAT PART AND TO PRODUCE A JOGGLE WITHOUT CRACKING. THIS IS SHOWN IN THE PART ABOVE THE YOKE. THIS WAS HYDROPRESSED AT TEMPERATURES OF 550°F AND 950°F. TEMPERATURE DIFFERENTIALS HAD NO APPRECIABLE EFFECT ON FINAL RESULTS.



EXAMPLES OF HYDROPRESS OPERATIONS ARE SHOWN ABOVE. THIS PART SHOWN HAS A STRETCH FLANGE WHICH WAS SATISFACTORILY ACCOMPLISHED, BUT THE SHRINK REQUIRED AT "A" COULD NOT BE ACCOMPLISHED AT 10,000 PSI. A RELIEF WAS ACCEPTABLE IN THIS AREA AND WAS USED TO AVOID FABRICATING A STEEL DRAW DIE. FRACTURED SECTIONS AT "B" ARE THE RESULT OF ATTEMPTED HAND FORM OPERATIONS AT TEMPERATURES OF 900° TO 1000°F.

PARTS 3 AND 4 ARE EXAMPLES OF SUCCESSFUL PARTS FORMED AT TEMPERATURES OF 850° AND 600° RESPECTIVELY.

FIGURE 10

Coupons sheared for bend tests revealed the laminating or separating effect caused by shearing. It was originally believed that these cracks would deepen when bent; however, this was found not to hold true as was revealed by sectioning a number of test coupons.

The best bends were accomplished by using an electrically heated platen and heated brake dies. Temperatures in the 550^{o}-$600^{o}F$ range were found to give best results. However, with material showing poor elongation it was necessary to form by staging and reheating between strikes.

Springback during brake forming was not consistent and required development for individual parts.

Heat helps reduce the springback problem and it improves the workability of titanium alloy where secondary operations are required.

The grain structure of titanium alloy became very apparent when brake formed. The bent area gave the appearance of fine cracks as an "orange peel" effect. However, a dye-check inspection did not reveal ruptures and lab tests indicated that no adverse affects resulted. (Reference Figure 11 page 45 - this photo is to the tenth magnification.)

FIGURE 11

MICROPHOTO OF THE OUTER SURFACE OF A TITANIUM SAMPLE BENT ON 5T RADIUS. THIS SAMPLE SHOWS THE CRAZED SURFACE FREQUENTLY EVIDENT ON COLD BEND SPECIMENS. HOT BEND SPECIMENS USUALLY SHOW A ROUGH OUTER SURFACE SIMILAR TO ORANGE PEELING. THESE CHARACTERISTICS ARE NOT EVIDENT IN ALL MATERIAL AND DO NOT SEEM TO HAVE AN EFFECT ON MATERIAL STRENGTH SINCE THEY ARE ONLY SHALLOW SURFACE MARKS.

Stress relieving at 1000°F after braking tended to reduce the brittleness created along the bend radii and reduced the tendency of the material to creep. This is mandatory before undertaking subsequent operations such as joggling or stretch forming.

3.2.9 Drop Hammer Forming

Attempts at drop hammer forming presented many problems. Due to the resistance to bending, slow elongation and excessive springback, it was necessary to develop drop hammer dies which would allow for overforming. (Reference Figure 12 page 47

In one part, the inter-nacelle fairing, several drop hammer dies were made. The first die was with normal contour and did not give any semblance of success due to the excessive springback. As a result, a second die designed to overform the part was made. The die was heated to 400°F and the material blank to 900°F. Satisfactory results were not obtained. A die was then built with punch and die inverted from the original design. This female setup produced better results, however the parts were not acceptable. This part was then redesigned to be made in three parts using the original dies and by hand finishing to final size, acceptable parts were made.

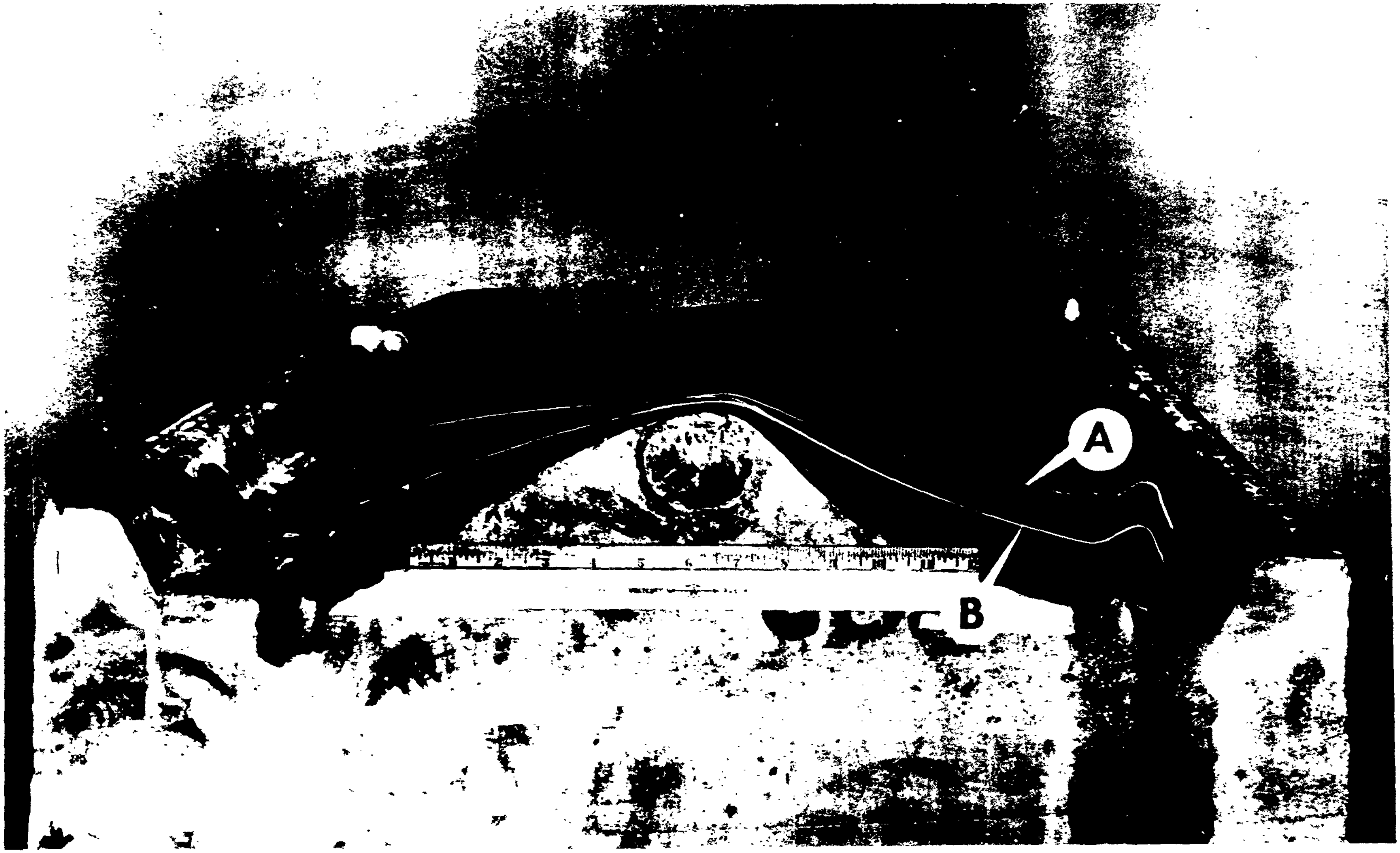


FIGURE 12

THIS PHOTOGRAPH SHOWS THE COMPARATIVE SPRINGBACK BETWEEN 1/4-HARD STAINLESS STEEL AND RS120 TITANIUM ALLOY. THE UPPER PART IS TITANIUM. THE LOWER PART IS OF 1/4-HARD STAINLESS STEEL. THE STAINLESS STEEL PART HAS THE CORRECT CONTOUR.

In order to conserve material, an angle-shaped part was formed to a closed degree on the brake. A drop hammer die having the required bend and joggle was then used to open and finish forming the part to shape. In this way, no material for trapping was required. (Reference Figures 13, 14, and 15, pages 49, 50, and 51)

3.2.9.1 Recommendations

Traps on drop hammer dies used to form titanium alloy are considerably lower than for stainless steel. The shape of these traps is more in the form of a low bead. Conventional traps are too high and cause ruptures which frequently destroy the part.

All drop hammer operations were performed by heating the material to 900°-1000°F.

Dies are run cold to eliminate mismatch.

Lead punches give satisfactory results on simple contours. Severe shapes require kirksite, or lead punches faced with mild steel.

3.2.10 Stretch Forming

Stretch forming titanium alloys can be best accomplished through the use of heated dies and form blocks. Dies for

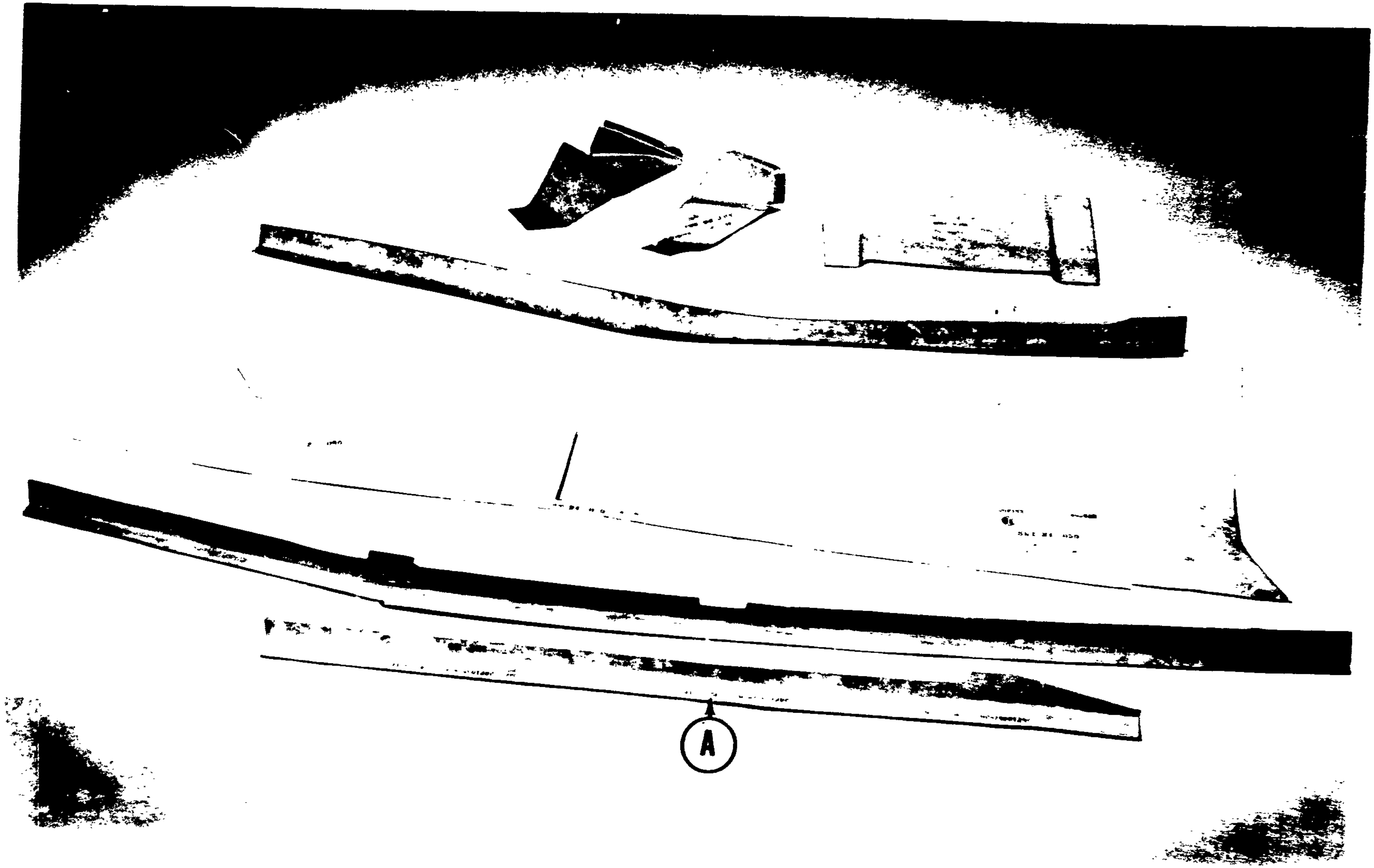


FIGURE 13

THESE DETAILS WERE DROP HAMMER FORMED FROM RS120 MATERIAL. THE LOWER ANGLE PART IS A VARIABLE ANGLE SECTION OF SLIGHT CONTOUR AND JOGGLE IN ONE LEG. TO CONSERVE MATERIAL, THIS PART WAS BRAKE FORMED TO A CLOSED DEGREE ANGLE, THEN SIZED ON A DROP HAMMER DIE, RESULTING IN SAVING IN TRAPPING MATERIAL NORMALLY REQUIRED IN DROP HAMMER DIES.

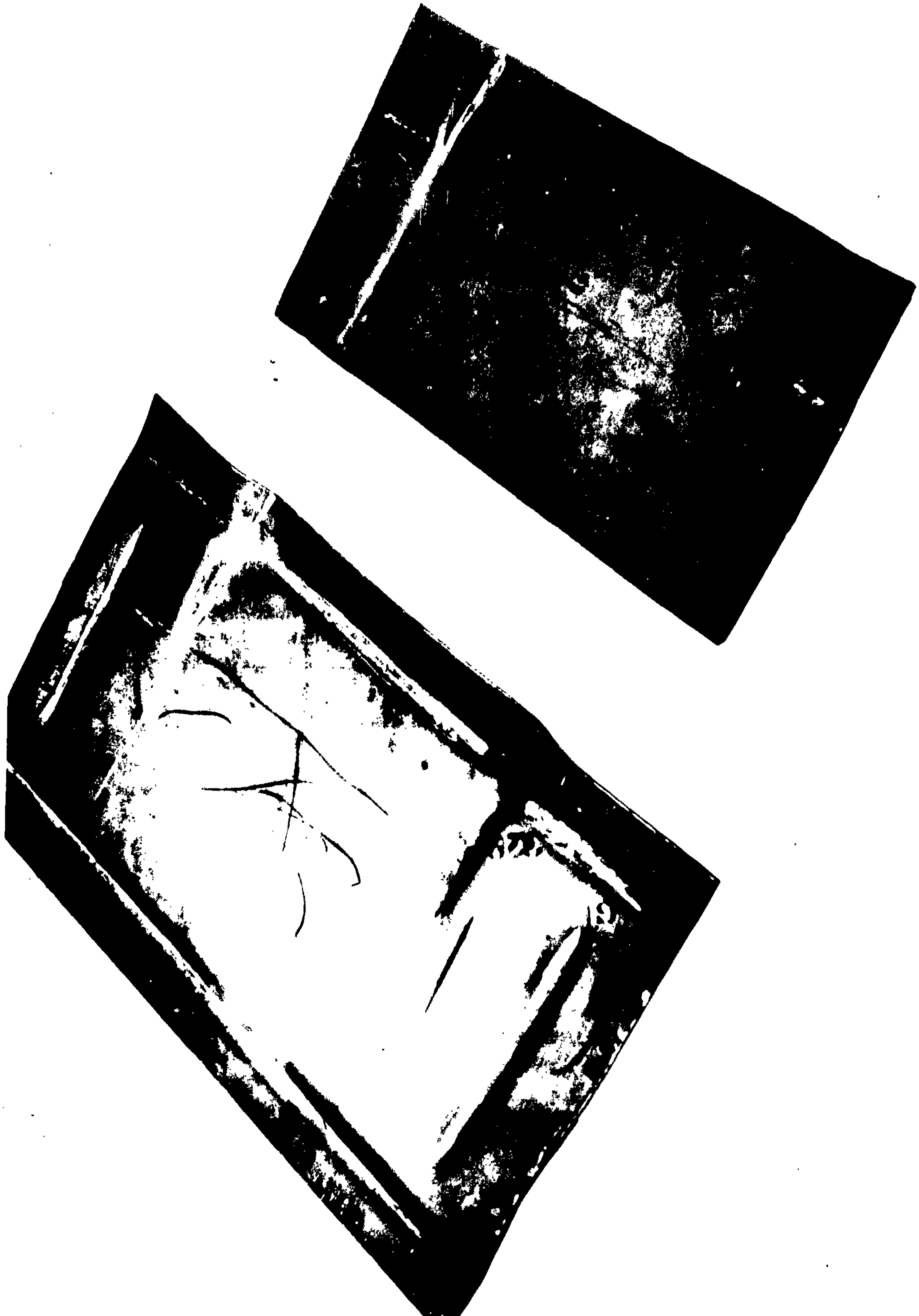


FIGURE 14
THIS PHOTOGRAPH SHOWS THE TYPE TRAPPING FOR DROP HAMMER DIE FORMING OF R120 TITANIUM ALLOY.

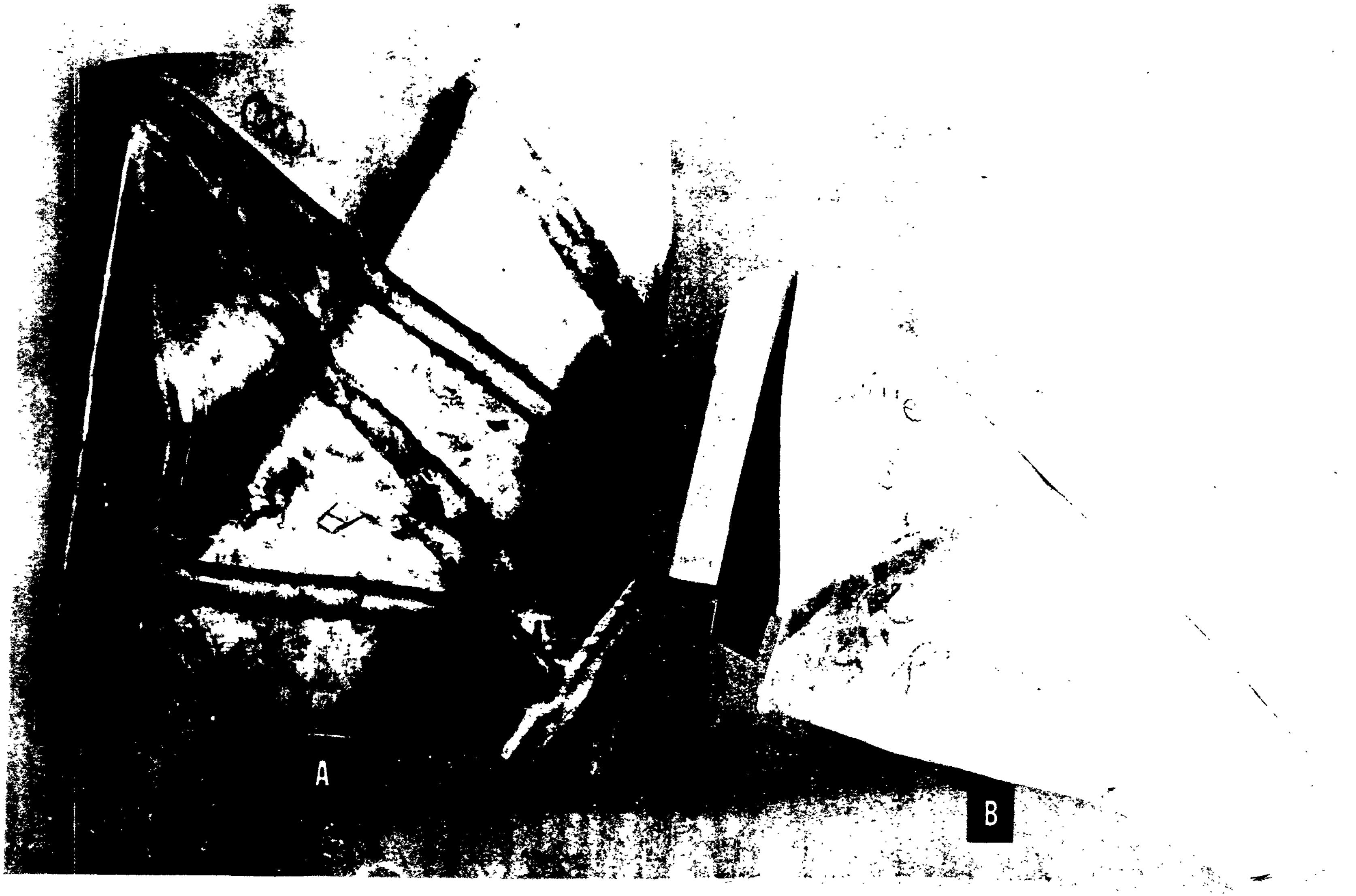


FIGURE 15

DROP HAMMER OPERATIONS ARE SHCWN ABOVE. THESE OPERATIONS WERE PERFORMED USING 900°F TEMPERATURE FOR THE TITANIUM MATERIAL WITH THE KIRKSITE DIE HEATED TO 400°F. HAMMER TECHNIQUE IS OF PRIME IMPORTANCE IN THESE OPERATIONS. PART "A" SHOWS TH CONFIGURATION OF MATERIAL AND THE TRAPPING USED TO PRODUCE THIS PART.

PART "A" ALSO SHOWS CRACKS IN NON-STRESSED AREAS OF THE MATERIAL. THIS IS FURTHER INDICATION OF THE PECULIARITY OF THE TITANIUM ALLOY.

formed sections must be built from material which can be heated to 600°F. Skin stretching can be accomplished at 450°F; skin stretch form blocks can be cast from kirksite. However, steel or aluminum should be used in the construction of section forming tools. The form blocks must be developed for springback. (Reference Figure 16 page 53)

The rate of elongation in stretching, even under elevated temperatures, is very low as the material must have time to move.

Strain hardening and material creep after forming also presented a fabrication problem. Material that had been formed to contours, when permitted to lay at room temperature 24 to 48 hours, showed a decided change in contour. Parts frequently developed cracks after 24 to 48 hours following stretch forming operations. Immediately after forming stress relieving at 1000°F for 30 minutes gave partial relief. All formed parts were given this stress relieving operation. The above conditions were worse when parts were stretch formed cold.

All stretch forming operations of preformed section parts were carried out by heating the form block to 600°F.

FIGURE 16

COMPARATIVE SPRINGBACK AND ELONGATION BETWEEN RS120 TITANIUM ALLOY AND ONE-FOURTH HARD STAINLESS STEEL ARE SHOWN ON THESE STRETCH-FORMED PARTS. THE CENTER PART IS RS120 TITANIUM ALLOY AND THE UPPER IS STAINLESS STEEL. THE STAINLESS STEEL PART IS OF THE CORRECT CONTOUR. ELEVATED TEMPERATURES DID NOT CORRECT THIS PROBLEM.

PARTS "A" AND "B" ARE TITANIUM ALLOY; BOTH WERE BRAKE-FORMED AT 550°F AND COLD STRETCH FORMED.

This was accomplished by use of a suitable gas burner under the block. The part was very slowly wrapped permitting it to absorb the heat on contact with the form block. A dwell time of one-to-one and one-half minutes after wrapping to permit full heat absorption was found beneficial. The contour was then set by stretching approximately two per cent. By holding the part under full pressure against the stretcher form, creep was reduced.

Hot brake forming of preformed sections improved the stretch form operation.

Localized necking or reduction in flange width was also encountered while no loss in gauge was experienced; loss in flange height in localized areas was noted. This was especially noticeable in sharp bend areas. In order to overcome this problem, excess material was added to the flange width. This excess was removed after forming. (Reference Figure 17, page 55)

3.2.11 Hand Forming

While no titanium alloy parts were fabricated by hand forming alone, considerable hand work was required for finishing various parts to required dimensions.

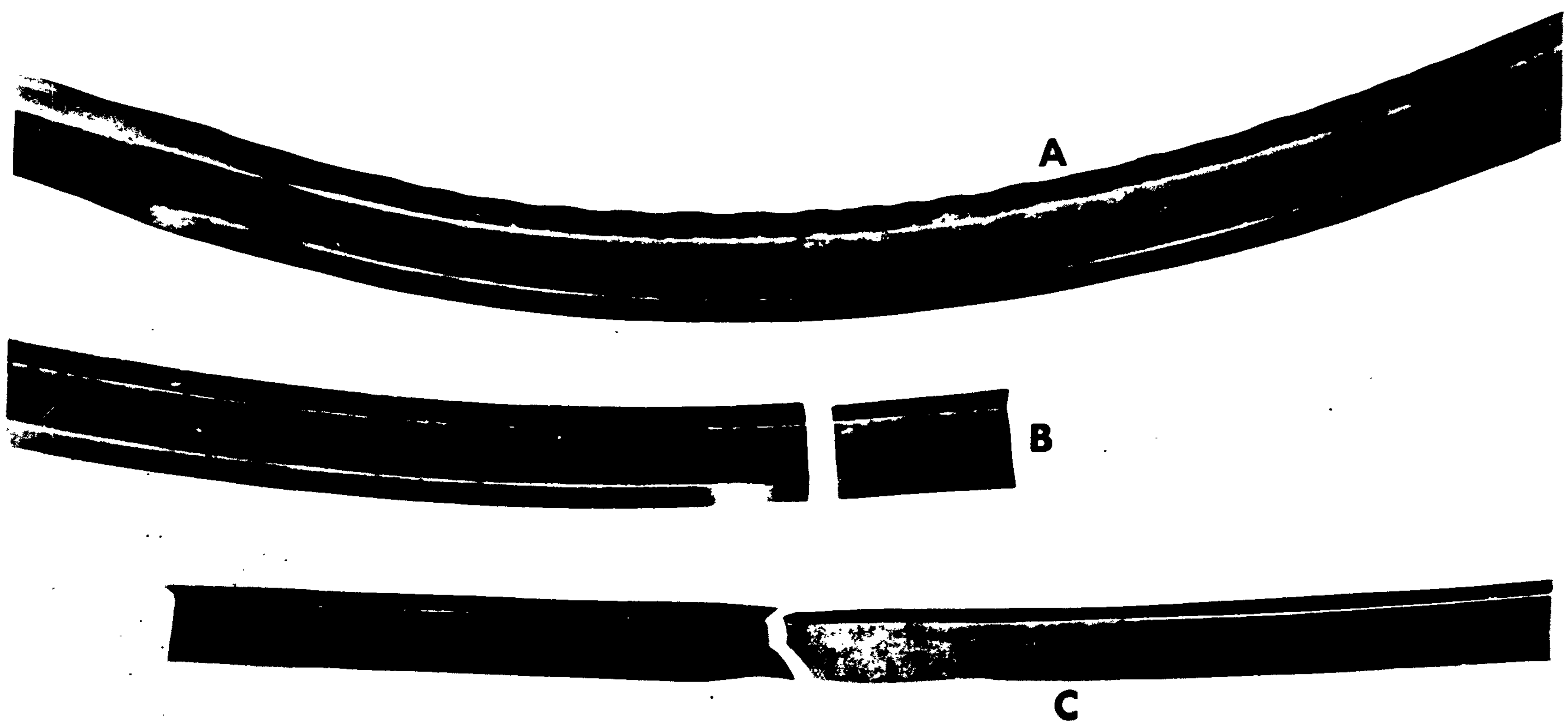


FIGURE 17

THE RESULT OF STRETCH FORM OPERATIONS ARE SHOWN IN THIS PHOTOGRAPH. THE TENDENCY TO NECK LOCALLY IS SHOWN BY THE LOWER PART WHICH WAS STRETCH FORMED AT 550°F. ELONGATION RESULTS FROM LOSS OF FLANGE HEIGHTS.

Due to the inconsistent results obtainable from the available material, hand finishing formed an important link in completing this project. The varied amount of springback, the curled flanges on draw formed parts, and the creep tendency of titanium alloys all combined to make hand finishing a necessity.

Hand work is a slow, difficult process. While hand work is acceptable on a limited project, such as replacing the stainless steel in the two J47 jet pod assemblies, it would not be acceptable on an extended production program.

All hand work was carried out by localized heating to 500°-600°F. By using suitable mandrels and heavy lead-faced hammers, it was possible to displace the material to the extent required for acceptance on assembly.

The use of hand and hydraulically actuated arbor presses was necessary on the heavier gauge materials. Using temporary type blocks and localized heating, pressure was exerted in the distorted areas until the required correction was obtained.

In order to reduce creep and strain hardening effects, stress relieving at 1000°F shortly after forming operations were completed, was utilized.

3.2.12 Joggling

Considerable difficulty was encountered in attempting joggle operations. Only steel joggle dies gave any semblance of success. Heating both the dies and material to 600°F and then over-forming resulted in an acceptable offset.

However, it was found necessary to extend the length of joggle travel to five and six times the depth to prevent cracking. In some parts this was not acceptable and a relief cutout, when acceptable, was incorporated to permit the necessary deflection.

The entire section must be joggled for good results. The side wall offers too much resistance to compression when only the top flange is joggled. (Reference Figure 18 page 58)

Some joggling was attempted on parts formed on the drop hammer. Here, too, it was found necessary to over-form to allow for springback. It also was necessary to increase

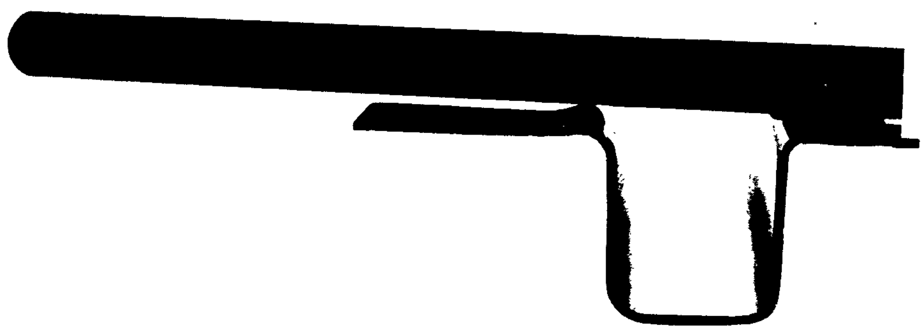


FIGURE 18
THIS PHOTOGRAPH SHOWS A CROSS-SECTION OF JOGGLED CHANNEL FABRICATED FROM RS120.

the length of joggle travel and to utilize heating to $600^{\circ}F$. The strains set up during joggle operations frequently will lead to cracks and distortion of the flat plane of the part. Where acceptable, this can be reduced by incorporating a relief cutout or joggling both planes of the part.

In order to reduce brittleness and ruptures following joggling, it was found beneficial to stress relieve at $1000^{\circ}F$ shortly after completing operations. (Reference Figure 19, page 60)

3.2.13 Dimpling

Titanium alloy dimples fairly well considering the difficulties encountered in other fabricating phases of the project. The chief requirement is adequate heat, and sufficient power for forming the dimple.

Equipment used in dimpling magnesium is suitable for dimpling titanium alloy. All burrs and sharp edges around holes to be dimpled must be removed in order to eliminate every possibility of cracking the material.

In dimpling operations a temperature of $600^{\circ}F$ was used. Permitting a short dwell time before actual dimpling

FIGURE 19
THIS PHOTOGRAPH SHOWS A COMBINATION OF HYDROPRESS OPERATIONS AND STEEL FORM DIE JOGGLE OPERATIONS.

to permit heat absorption, coupled with a slow ram descent, gave good results. Cracking usually could be traced to incomplete deburring, insufficient heat or too quick a ram thrust. Only very slight hole enlargement was noted; this compared favorably to stainless steel.

3.3 Machining

Machine operations required the development of cutters, machining techniques, and coolant applications.

Ridigity of machine and set-up are important factors of machinability. These factors should be continually stressed.

Cutting lubricants became critical as did cutting feeds and speeds. Highly chlorinated cutting oils have benefited cutter life and surface finish. Operations were not extensive enough in scope to be conclusive but indicated that highly chlorinated oils increase cutter life up to 300 per cent. (Reference Figure 20, page 63)

3.3.1 Milling

Face mill and slab mill operations produced good surface finishes. With the Ti-150 and Mallory-Sharon 3AL-5CR alloy forgings, cutter life with high speed steel or carbide compares with that when cutting aircraft steel SAE4340 heat treated from RC42 to RC44.

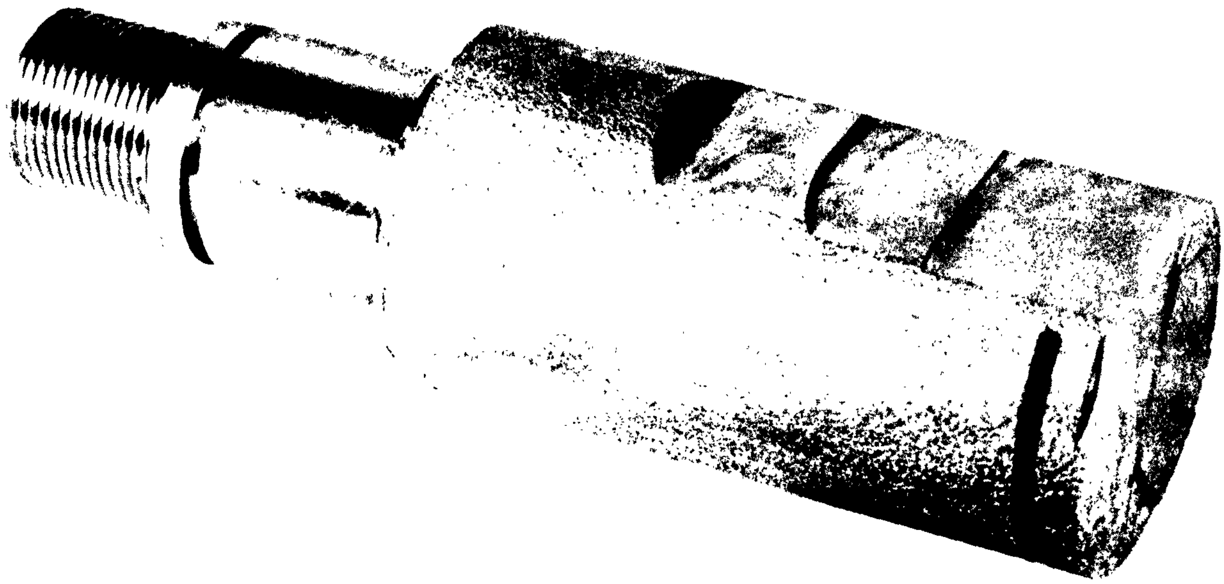
Cutting oils are more critical for titanium than for steel, which makes the selection of a proper cutting oil so important.

Cutters with positive rake angles produced both better cutter life and better finish. Cutter speeds of 35 to 40 surface-feet-per-minute for high speed steel, and 80 to 100 surface-feet-per-minute for carbide, gave the best cutter life.

Rigidity of machine and machine set-up is just as important for mill operations as for any other machine operations.

3.3.1.1 Recommendations

Positive rake angle tools similar to those used for aluminum should be used. Carbide should be used for cutting tools whenever possible, and all milling operations should be run with a proper cutting oil. Rigid machines and machine set-ups should be used at all times.



THIS PHOTOGRAPH SHOWS TURNING OPERATIONS ON A FORGED BILLET. THE HEAVY FEEDS SPECIFIED IN MOST REPORTS WERE NOT SUCCESSFUL BUT FEEDS OF .008 TO .010 WERE SATISFACTORY. THE GROOVE IN THE LARGE END OF THE BILLET INDICATES AN UNSUCCESSFUL ATTEMPT TO CUT THE BILLET USING AN ABRASIVE CUT-OFF WHEEL. THE CUTS ON THE UPPER SURFACE OF THE BILLET WERE ACCOMPLISHED USING A FACE MILL.

FIGURE 20

3.3.2 Turning

Surface scale approximately .040-inch was encountered on round bar stock. A 100 surface-feet-per-minute at a feed of .005 PR produced the best results. Standard grade carbide tools gave little success as the tool had to be ground after each cut. Best results were obtained with a K3H Carboloy cutting tool ground with a positive rake and clearance angle.

After the hard scale was removed, machining was comparable to 18-8 stainless steel. On the basis of this test, all turning operations were accomplished on the production parts.

3.3.3 Threading

Twenty-four holes were tapped with a standard 3/8 x 16 tap ground for cutting steel. Speed was 20 rpm, approximately two surface-feet-per-minute. Cimcool was used in its concentrated form as a lubricant for tapping. At this speed tapping was accomplished with comparative ease. A faster speed of 31 rpm was then tried with little success. The tap would squeak and bind and eventually break at this speed. At the slower speed, the 24 holes were finished with no apparent wear on the tap.

Based on this experience, it is estimated that the tap should have a life of 200 to 300 tapped holes.

3.3.4 Drilling

High-speed drills stand up well at speeds of 20 to 25 surface feet-per-minute with feeds of .002 to .003 inches per revolution using sulphur-base cutting oil as the coolant. Increase in speeds or in feed rate reduces drill life.

The speeds and feeds as used for carbon steel tools on cast steel material serve as a fair guide for titanium drill operations.

In drilling sheet titanium, such as detail parts for assembly operations, it is imperative that pressure be maintained in order to assure constant cutting action. Otherwise, heating and work-hardening will become a problem.

Air-pressure operated hand drills are preferred to electrically powered drills because of their lower speeds and the constant control of their speeds in drilling.

3.3.5 Profiling

Profiling operations on .375 plate were accomplished on a Cincinnati Hydrotel at 356 rpm using a high-speed steel end mill. Cimcool was used on all cutting operations as a coolant.

The roughing cut was made at seven inches per minute. The finish cut was made at four inches-per-minute feet with the removal of approximately 1/32 inch material. The finish produced by this profiling operation was very good.

RESISTANCE WELDING

SECTION IV

RESISTANCE WELDING

4.1 Introduction

In view of the lack of information on spot welding titanium alloy, it was decided to investigate its welding potential on both ac and dc type spot welding machines.

In the past Convair had used a minimum tensile over-shear ratio of 0.25 as a control factor. It was decided that this T/S ratio would be the target for this work. All work was accomplished using RS-120 titanium alloy.

4.2 Recommendations

Until such a time as material properties such as hardness, surface finish, chemical analysis, tensile strength, etc. becomes uniform, spot welding of RS-120 does not appear feasible.

4.3 Procedure Development

Using stainless steel settings as a starting point, a parameter of 27 spot welds was run on both the Acme ac and the Taylor-Winfield dc machines. These welds were macrosectioned and examined for nugget size, penetration, and soundness. On the basis of the macroexamination of the above welds, several machine settings were chosen for both ac and dc-type spot welders. Tensile and shear coupons were made at these settings and tested.

The nuggets of all of the welds produced were surrounded by a heat affected zone in which certain metallurgical changes had taken place that were not fully understood.

It was considered possible that absorption of oxygen, carbon or nitrogen might be a cause for the embrittlement of the welds. To explore this possibility, welds were made on both types of machines using argon gas to envelope the faying and electrode surfaces. The results did not show any appreciable change.

T/S ratios in the order of 0.19 were obtained. All spot welds having a shear load of greater than 1200 pounds showed expulsion of the hot metal at the interface of the weld. It is possible that this expulsion was correlated to the low tensile values of these high shear welds.

A third type machine (three-pase dc) was tried. This machine is capable of welding a wider range of materials because of the added controls and closer control over existing variables.

The results obtained from this machine proved very encouraging. The shear strengths were better than that required for one-half hard stainless steel and the tension strengths were considerably better than those obtained previously.

The welds were still somewhat brittle, but they lost the extreme brittleness which characterized the previous welds. As stated before, early welds had a concoidal fracture and broke through and around the welds indiscriminately. The welds made with the three-phase machine had ductile type fractures and the entire nugget was pulled from both coupons. The nuggets greatly resembled those found in the stainless steel.

All of the above tests on the three-phase machine were accomplished using material from one sheet. When the parameters for the best settings were investigated, to improve the weld quality and to determine the critical limits, the original results could not be duplicated with material from a different sheet of material. In fact, it was found that welds could not be consistently reproduced in different areas of the same sheet.

The following is a summary list of the difficulties involved in the spotwelding of RS-120 titanium alloy.

1. The spotwelding characteristics of RS-120 sheet material varies from sheet to sheet. It was not possible to reproduce results from one sheet to another. Machine settings which gave good results on one sheet, had to be varied more than the 10 per cent allowed on other sheets. Each sheet was a separate problem, involving the determination of a new set of machine settings. This procedure is not too involved but could require a certification for each sheet to be spotwelded.

2. The problem of varying sheet thickness involved the further consideration of certifying for various thicknesses in the same sheet.

3. The problems involved in spot welding RS-120 titanium alloy were undoubtedly a function of the variations found in the sheets such as:

   A. Variation in surface finish

   B. Variation in hardness (24 to 36 Rockwell "C")

   C. Variation in chemical composition - Manganese varied from 4.93 to 8.01 per cent, carbon varied from 0.04 to 0.10 per cent

D. The tensile strength varied from a low of 127,000 psi to a high of 158,300 psi.

4. The machine settings must be held very close and were difficult to establish. The only way to determine the settings is to use an oscillographic record to determine the relationship between current and forging time. This was found to vary from sheet to sheet.

5. The RS-120 titanium alloy appeared to have a shunting effect which was much more predominate then the same effect in stainless steel. When multiple spot welds are made, the settings obtained for one spot weld would have to be varied considerably to produce satisfactory welds.

6. When multiple sheets are to be spot welded, the machine settings will have to be adjusted to facilitate welding the sheet in the combination with the poorest spot welding characteristics. (Reference Figure 21, page 73)

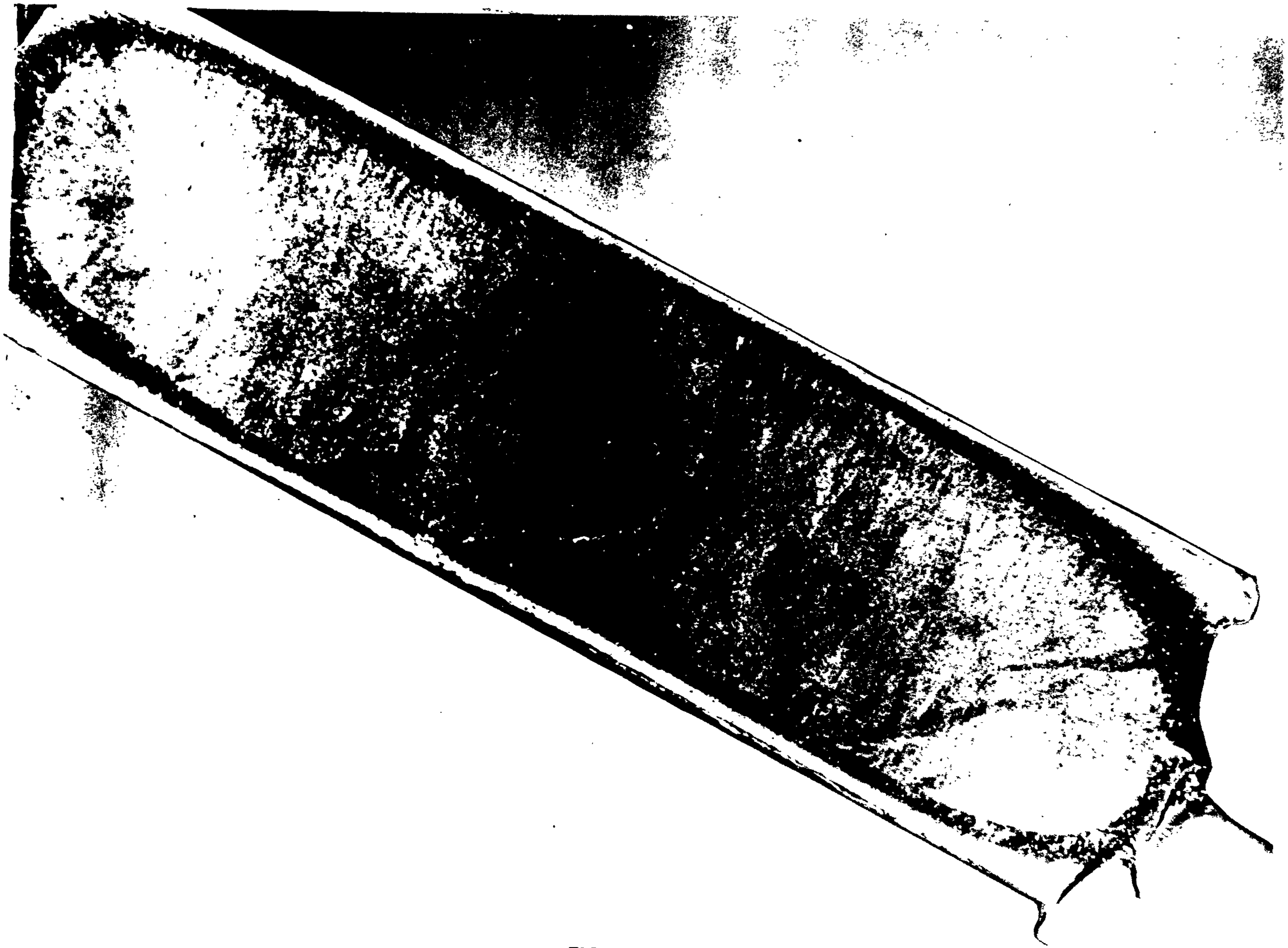


FIGURE 21

THE CROSS-SECTION OF THE CAST WELD NUGGET ABOVE SHOWS THE COLUMNAR STRUCTURE OF THIS TYPE WELD. BRITTLENESS IS INDICATED BY THE FRACTURE OCCURRING IN THE HEAT AFFECTED ZONES AND BY THE LACK OF ELONGATION IN THE WELD AREA. ALL STRESS TESTS ON VARIOUS MATERIAL SHEETS SHOWED THIS TYPE WELD.

SECTION 5

FORGING

SECTION V

FORGING

5.1 Recommendations

Apparently, the forging of titanium is no more difficult than the forging of 75S aluminum; however, more preliminary stages are needed in the dies than are normally used in forging steel. The dies for all of the titanium forging operations were heated to between 240° - 300°F. This temperature was maintained throughout the forging operations.

It is recommended that billets be ground before forging to remove surface imperfections. While such imperfections apparently are not severe enough to cause defects in the forged part, a better finished part is obtained from the ground billet.

5.2 Procurement

In the future when it becomes necessary for Convair to specify the size of billet which will be used for titanium forging, such sizes should be from three-to-five per cent less in cross-sectional area than that used when making the same forging from steel. This is necessary because normally three-to-five per cent is lost in scale on steel parts which is not the case with titanium.

5.3 Materials

Forging billets were furnished by Titanium Metals Corporation and Mallory-Sharon Titanium Corporation. Those billets furnished by Titanium Metals Corporation carried their specification of Tl-150, while those furnished by Mallory-Sharon Titanium Corporation carried their specification 3AL-5CR alloy. The surface conditions of the billets appeared very rough. Convair suggested that these billets be ground, however Titanium Metals Corporation stated that this would be unnecessary.

5.4 Fabrication

The forging of titanium was accomplished in two forging hammers. The edging and blocking was accomplished in a 8,000-pound steam hammer and the finishing was accomplished in a 5,000-pound steam hammer. It was felt that the breaking down of the billet would require more power than the finishing because of the inherent tendency of titanium to resist compressions. It was also felt that less flow-through would be encountered in the finishing die if it were accomplished on a smaller, or 5,000-pound hammer.

The following is a detailed procedure of the forging of each individual titanium part. (Convair part #36P10354)

Part No. 1 was heated at 1640°F and carried at this temperature all the way through the forging operation. The part did not fill and there were shuts on the rib sections. (Reference Figure 22, page 78)

Part No. 2 was heated at 1640°F, fullered, rolled, reheated to 1600°F, blocked, and finished, reheated to 1700°F, restruck in the final stage and trimmed. Considerable difficulty was encountered in trying to fill all parts of this forging.

Part No. 3 was heated to 1640°F, fullered, rolled, and reheated to 1700°F, reblocked and finished, reheated to 1700°F and restruck in the finish die. There was very little reduction of cross-sectional area in restriking in the finish die.

Part No. 4 was heated to 1850°F and carried all the way through the forging operation; however, the part cooled before it could be trimmed, therefore it was reheated to 1200°F and trimmed.

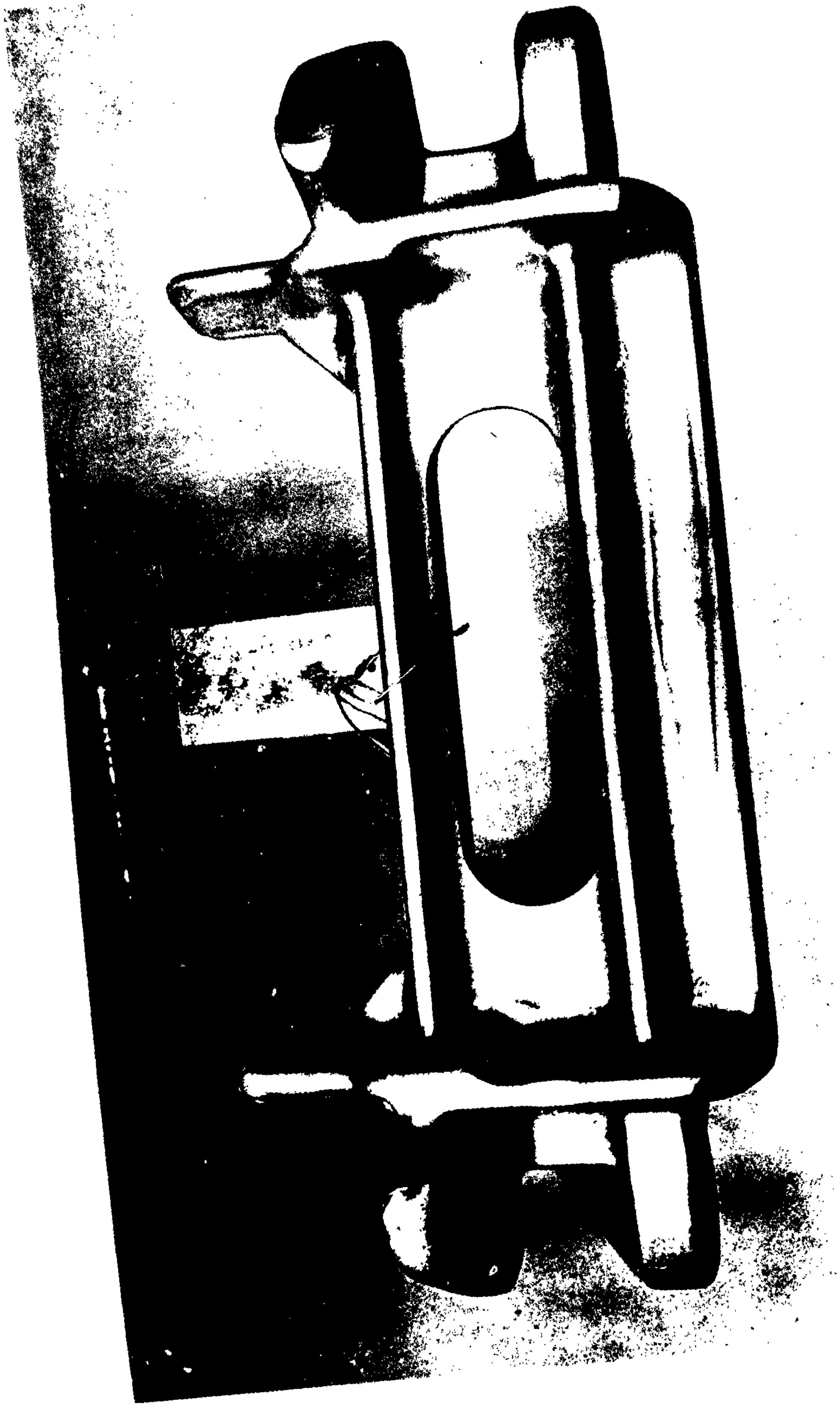


FIGURE 22
IMPERFECT FORGING SHOWING SHUTS AND UNFILLED AREAS.

Part No. 5 - Same as part No. 4 except it did not require reheating for trimming.

Part No. 6 - Same as part No. 4.

Part No. 7 - Same as part No. 4 except a longer tong hold was drawn on the billet. This was to reduce the volume of material. The billet was flattened on two sides reducing it to approximately 4 3/8 inch. The part did not require reheating for trimming.

Parts Nos. 8, 9, 10, 11, and 12 - Same as Part No. 4 except no reheating for trimming was required.

Convair Part No. 36P10353 - All 15 of the titanium parts were handled in the same manner. They were heated to 1670-1700°F, carried all the way through the forging operations, trimmed, and restruck in the finish die. There was one shut apparent in all these forgings but this was unimportant to the finished part.

Parts Nos. 16 and 17 of the same Convair number were forged from stock which was furnished Convair by Mallory-Sharon Titanium Corporation as a sample. These billets were heated to 1850°F and handled in the same manner as the preceeding 15 parts.

Convair Part No. 36P10356 - All five of these titanium parts were heated to 1070°F and carried at that temperature all the way through the forging operations. These apparently were the most successful forgings made.

5.5 Heat Treatment and Processing

The temperature in the furnace for the titanium forgings was controlled by a portable potentiometer and an optical pyrometer.

The dies for all the forging operations were heated to between 240-300°F. This temperature was maintained throughout the forging operations.

Heating of the billets was based on the recommendations of a metallurgist for Titanium Metals Corporation. It was originally intended not to heat the billets above 1670°F and that all forging operations were to be accomplished before the temperature dropped below 1350°F. However, seeing the amount of reduction accomplished in these forging operations it was felt that the higher heating was acceptable for the initial heat, and reheat as many times as necessary to make the part so long as there would be at least 15 per cent reduction in cross-sectional area between each heat. It was stated that this would insure the physical properties.

Billets were placed in an electric heat-treat furnace and brought up to 1400°F before placing in the forging furnace.

It was recommended that the forgings be stress relieved at 1200°F for a period of 48 hours and then air cooled. This operation was satisfactorily accomplished at Convair. (Reference Figures 23, 24, 25, and 26, pages 82, 83, 84, and 85)

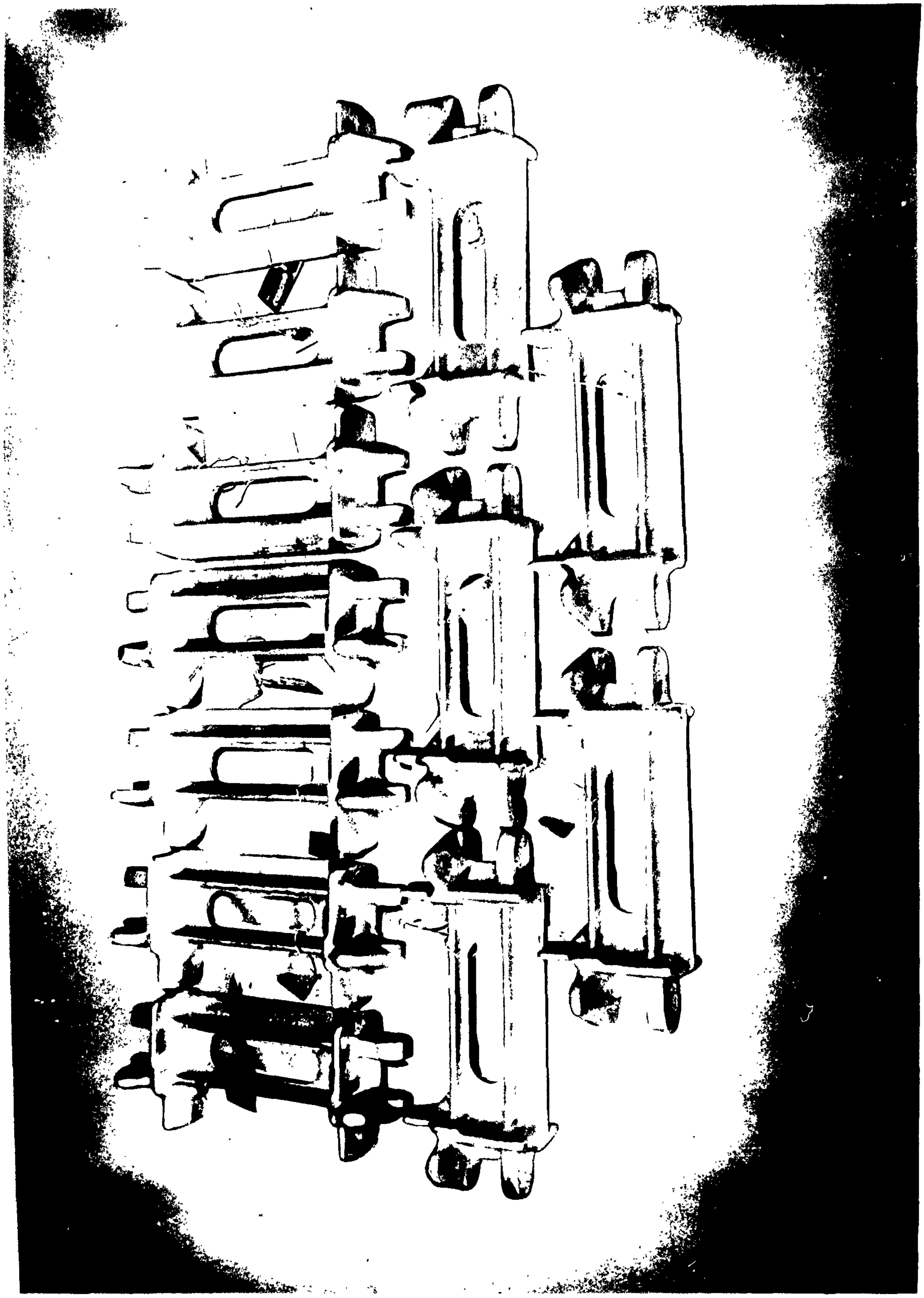


FIGURE 23
FORGINGS PRODUCED FROM TI-150A MATERIAL.

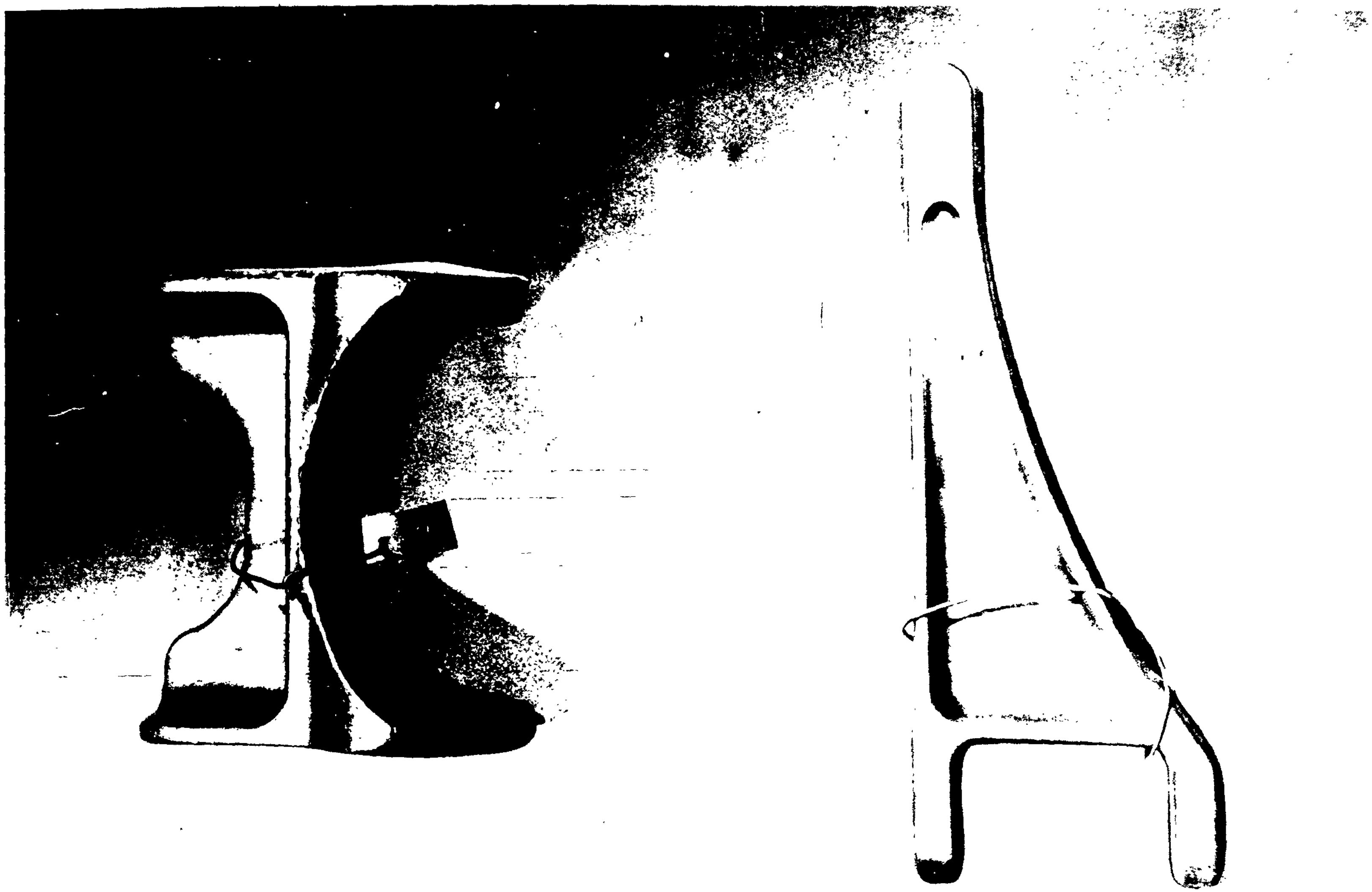


FIGURE 24

CLOSE-UP VIEW OF TWO TYPES OF REQUIRED FORGINGS.

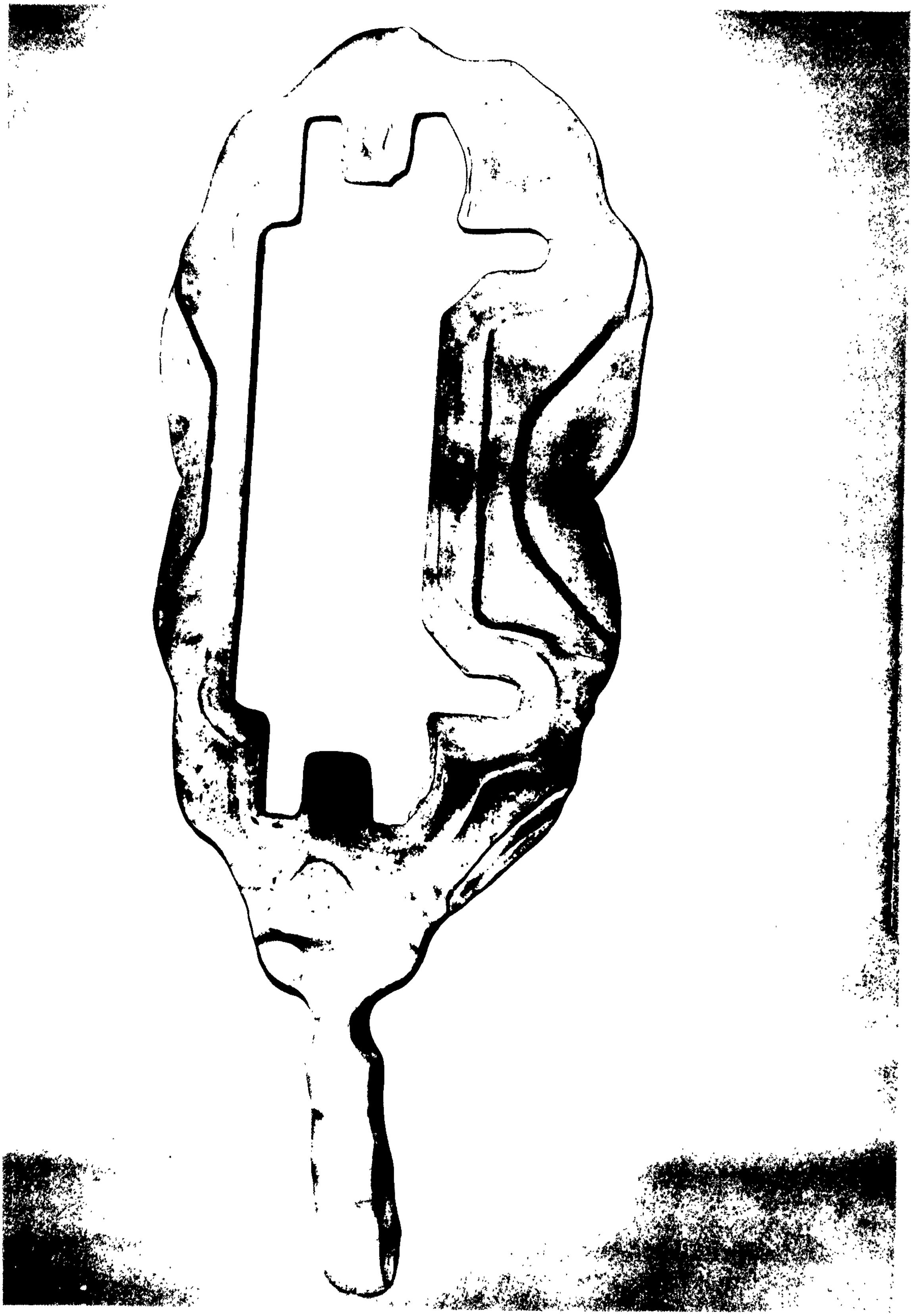


FIGURE 25
FORGING FLASH SHOWING GUTTERS AND TRAPS USED TO RESIST LATERAL FLOW.

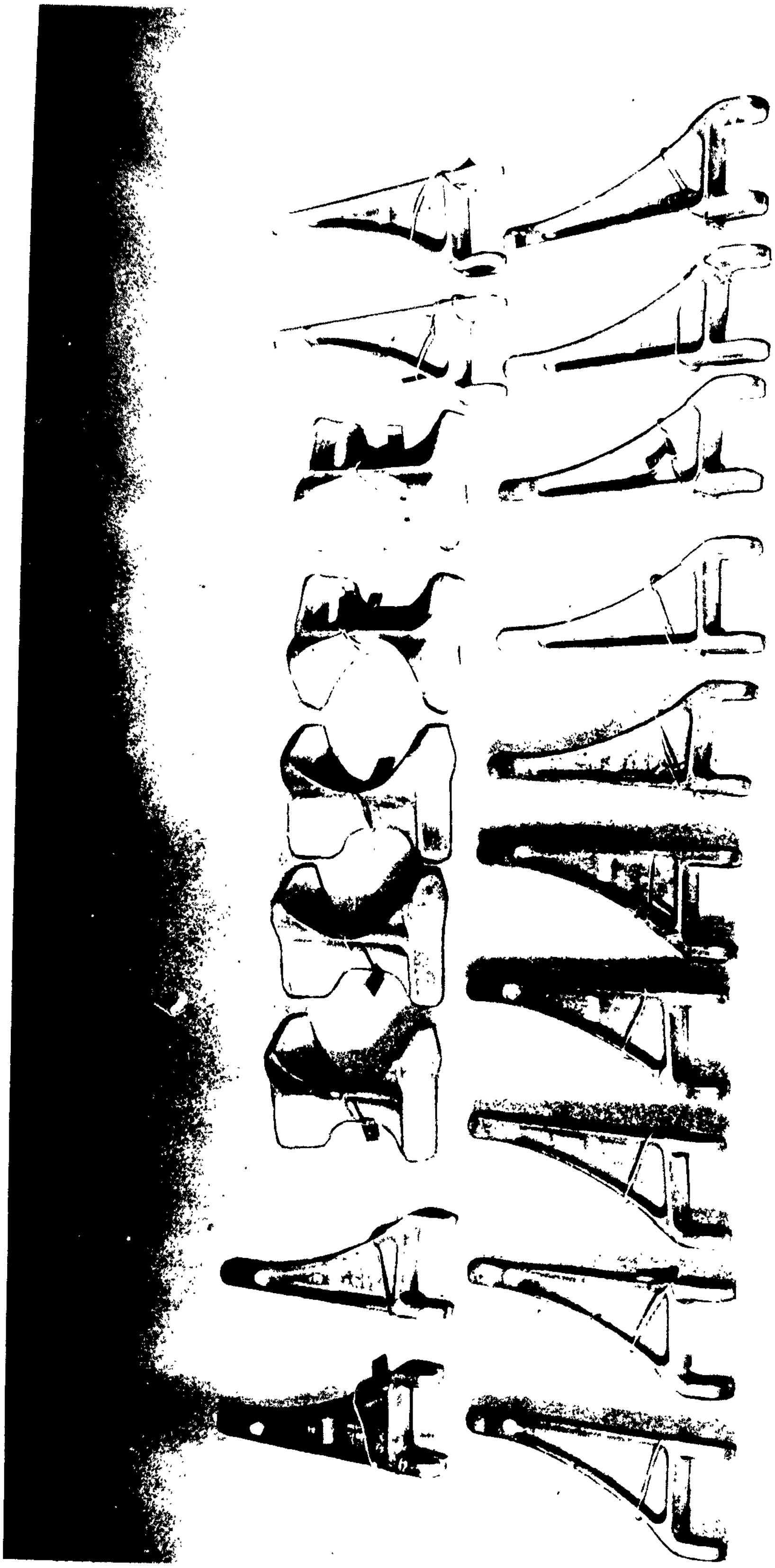


FIGURE 26
TWO TYPES OF FORGINGS REQUIRED FOR TITANIUM JET POD PROGRAM.

SECTION 6

ASSEMBLY

SECTION VI

ASSEMBLY

6.1 Recommendations

The assembly of titanium alloy details presented problems not normally encountered in assembly operations.

It is important that detail parts be formed to the exact required diminsions. Assembly of parts under strain, created stresses within the assemblies which frequently developed into cracks. The cracking of parts after assembly usually occurred in those details which were formed from material having low elongation, and high ultimate tensile strength. Stress relieving all parts to reduce brittleness and forming strains became mandatory. (Reference Figure 27, page 89)

Torque created in bolting sheet metal parts created strain which resulted in cracking. It is important that holes drilled through such assemblies, both for bolts and rivets, be at 90 degrees. When holes are drilled off-angle to the surface plane, and bolts and rivets drawn up tight, uneven strains are created which leads to material cracking after assembly. The experience gained in the assembly of the two J47 jet pods, pointed out the necessity of properly formed parts, stress relieve, and for the attention to details in assembly operations. All are important points in making acceptable assemblies from titanium alloy materials. (Reference Figures 28, 29, and 30, pages 90, 91, and 92)

FIGURE 27

ABOVE ARE THREE PARTS WHICH DEVELOPED CRACKS SEVERAL DAYS AFTER ASSEMBLY. **PRECAUTIONARY STRESS RELIEF OPERATIONS** HAD BEEN PERFORMED. LATER THESE PARTS WERE MADE WITH NO **SUBSEQUENT DIFFICULTIES RESULTING.**

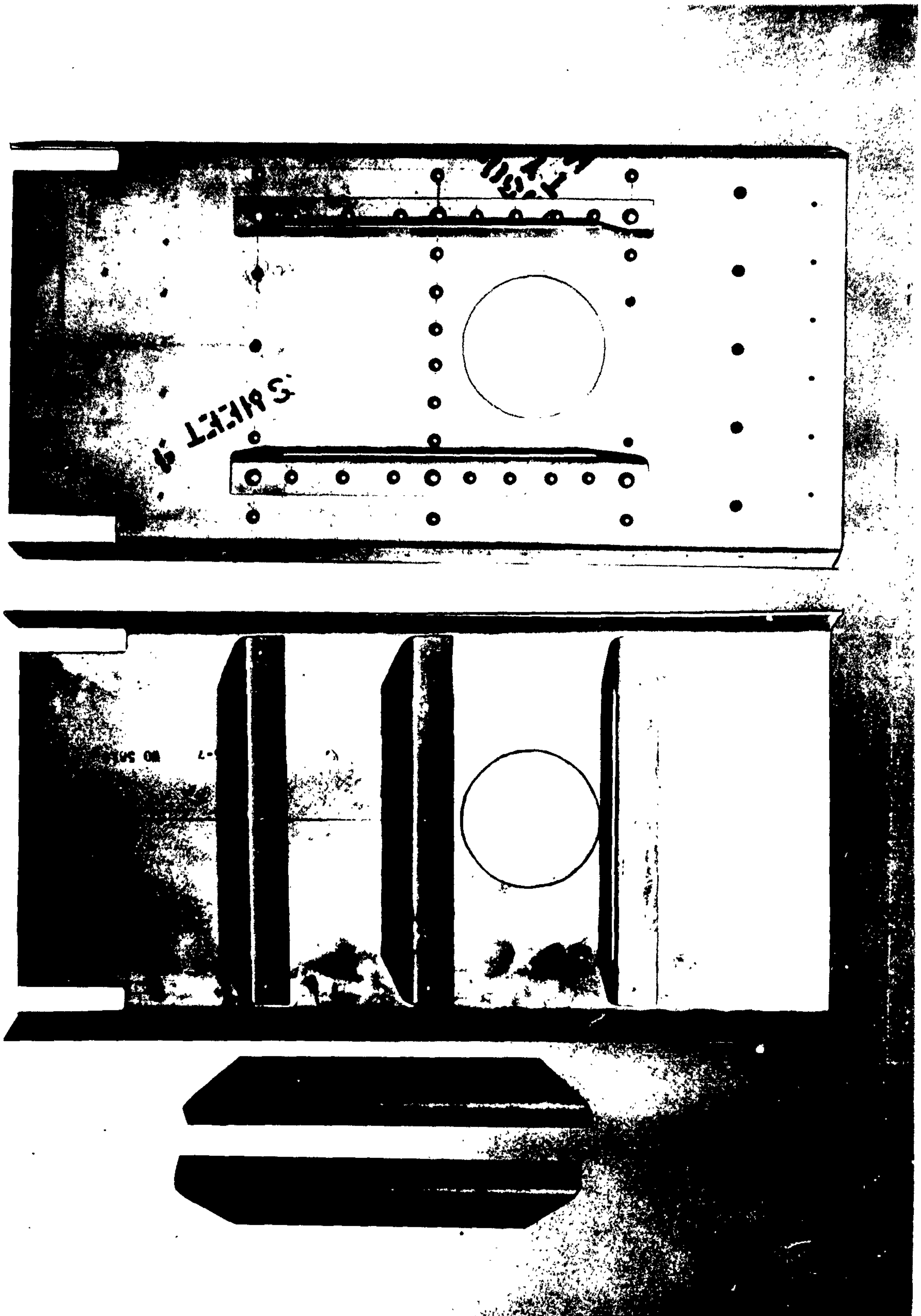


FIGURE 28

THE ABOVE PARTS ARE FRONT SPAR WEBS USED IN THE FABRICATION OF THE TWO FLIGHT TEST PODS.

FIGURE 29

THE REAR SPAR TERMINAL INSTALLATION PICTURED HERE IS ONE OF THE TWO SUPPORT POINTS FOR THE ENTIRE JET POD NACELLE ASSEMBLY. THE FOUR HEAVY PLATES (.375 INCH THICKNESS) AND THE CENTER FORGING ARE TITANIUM ALLOY.

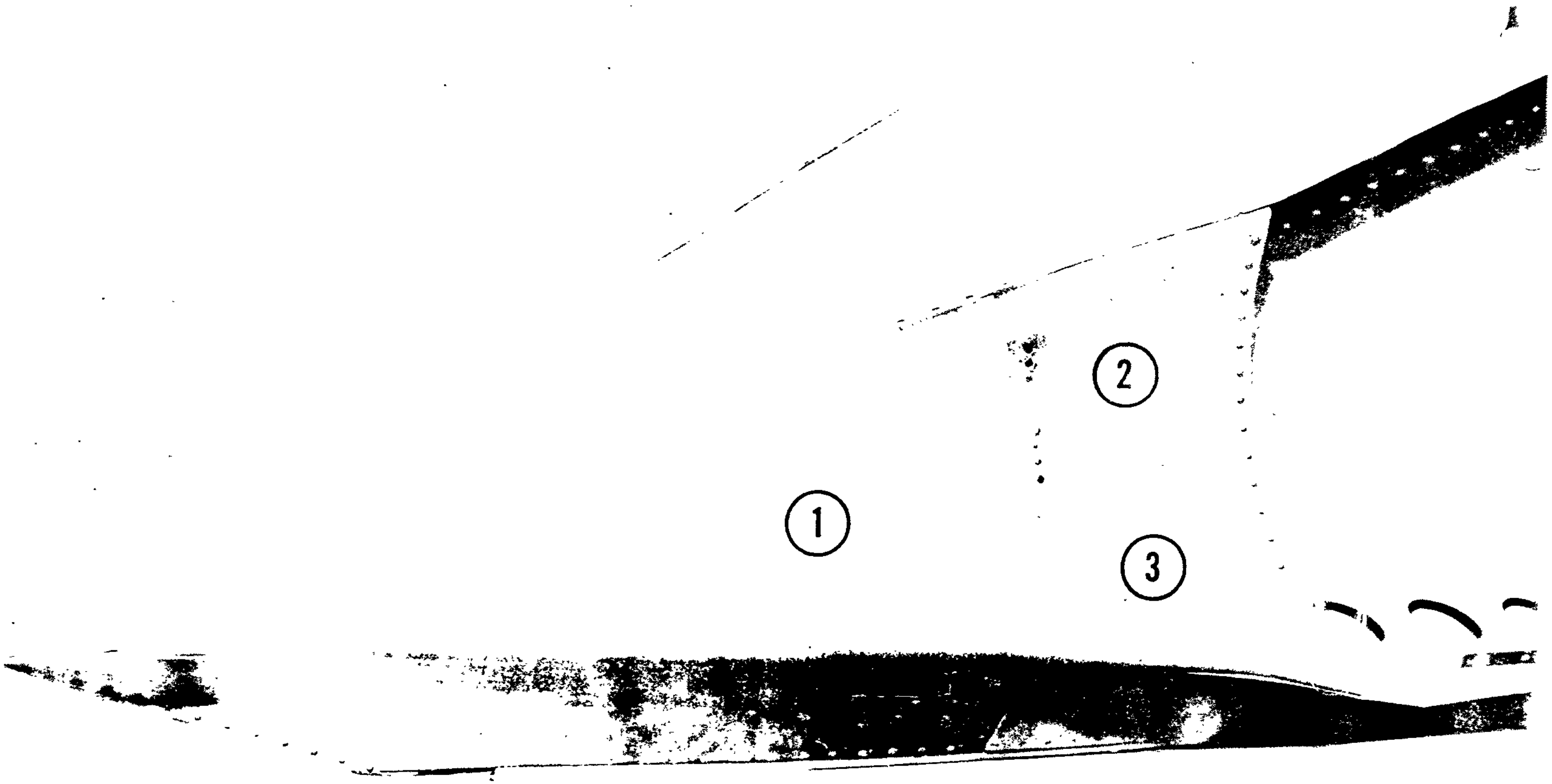


FIGURE 30

THE SIDE PANELS OF THE INTER-NACELLE FAIRINGS WERE SATISFACTORILY FORMED IN THREE PIECES WITH MONEL RIVETS USED IN THE SPLICES. ALL ATTEMPTS TO MAKE THEM IN ONE PIECE FAILED.

SECTION 7

HEAT AND SURFACE TREATMENT PROCESS

SECTION VII

HEAT AND SURFACE TREATMENT PROCESSES

7.1 Heat Treatment

The heat treatment of titanium alloy, except as noted for forgings, as commonly interpreted, was not used. However, the application and use of heat throughout the fabrication processes was used where it proved beneficial. The application of heat in sheet metal fabrication definitely demonstrated that ductility could be improved.

7.1.1 Limitations on Heating for Forming Operations

In the application of heat for forming of titanium alloy, a maximum of $1000^{\circ}F$ was established. Temperatures above $1000^{\circ}F$ created a scale which was difficult to remove completely. It is felt that temperatures above $1000^{\circ}F$ should be avoided.

Throughout the fabrication procedures definite temperatures were noted for forming operations. Such temperatures were established as the most suitable and gave the most consistent results for a given operation. However, due to the wide variation in ductility of titanium alloy, it was frequently necessary to deviate from established temperatures.

7.1.2 Stress Relieve

Stress relieve of titanium alloy was accomplished in a salt bath, as was used for the heat treatment of aluminum alloys, at 900-925°F. The parts were immersed for a period of 30 minutes maximum and then slowly cooled at room temperatures. An alternate method of heating in an electrically controlled hot circulated air oven at 1000°F for a maximum of 30 minutes, and then cooling at room temperatures was used. (Reference Figure 31, page 96)

7.1.3 Annealing

Due to the lack of facilities necessary to anneal parts in an inert atmosphere, it was impossible to anneal titanium at the required temperature. As a result, only a partial anneal was accomplished at the temperature and techniques given for stress relieving.

7.2 Surface Treatment

7.2.1 Degreasing

The removal of lubricants, dirt, oil, grease, etc. was accomplished by vapor degreasing and followed by an alkaline electro-cleaning operation. This is an anodic cleaning process using an alkaline-water solution at a temperature

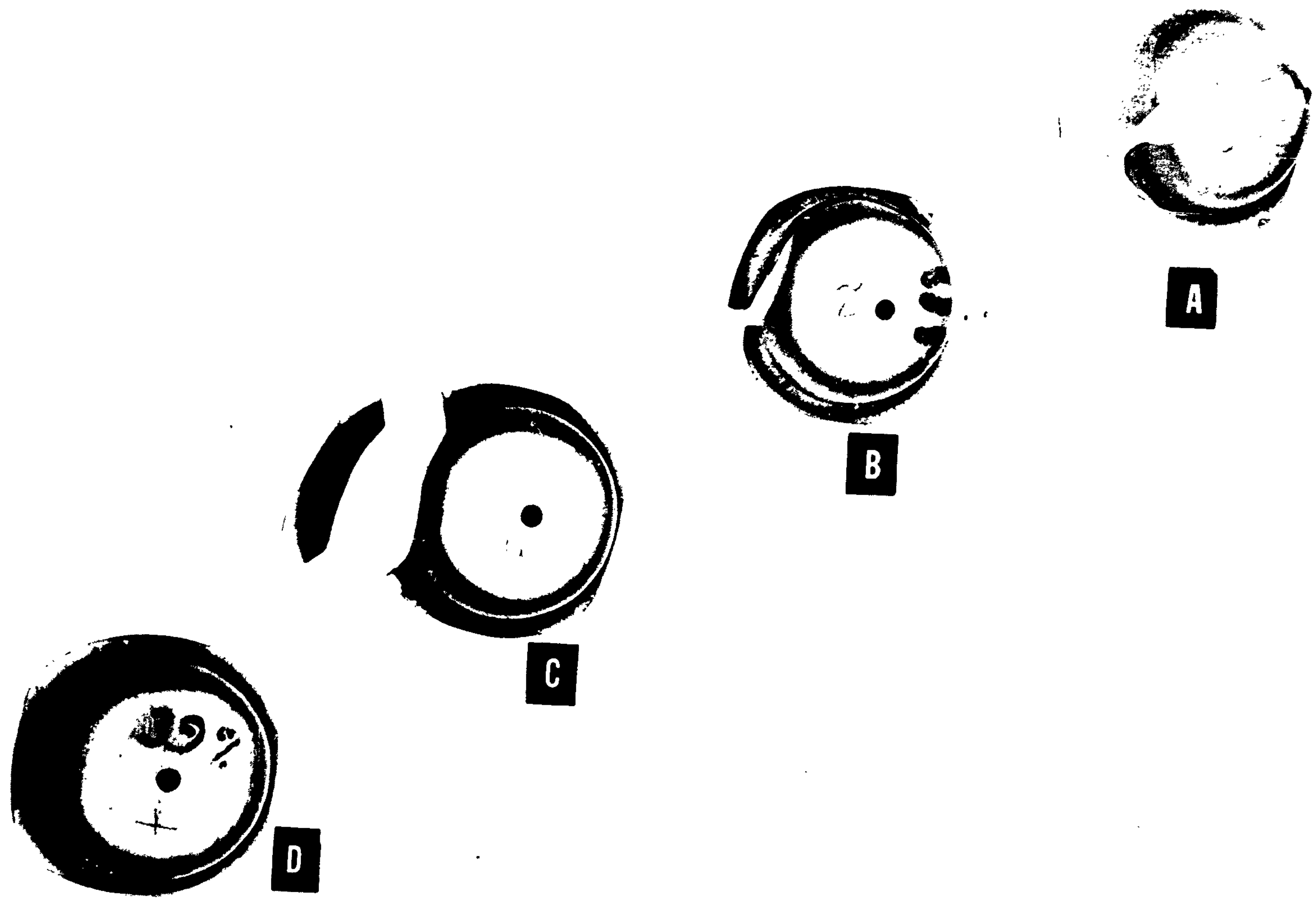


FIGURE 31

EXAMPLES OF DRAWING OPERATIONS ARE SHOWN ABOVE. THESE PARTS WERE DRAWN COLD AND PARTS "B", "C", AND "D" WERE GOOD AT THE TIME OF THE DRAWING. THE CRACKS IN "B" AND "C" APPEARED APPROXIMATELY 12 HOURS LATER AND CONTINUED TO GROW THROUGH A 4 DAY PERIOD INDICATING INTERNAL STRESS. PART "D" WAS STRESS RELIEVED AT 750°F AT THE TIME THE CRACKS APPEARED IN "B" AND "C". NO FRACTURE HAS OCCURRED IN "D". THE REDUCTION IN THIS OPERATION IS APPROXIMATELY 39%. PART "A" FRACTURED DURING THE DRAWING OPERATION. THIS PART WAS FROM A DIFFERENT SHEET OF MATERIAL THAN PARTS "B", "C", AND "D", WHICH INDICATED THE INCONSISTENCY ENCOUNTERED IN THIS TITANIUM ALLOY.

of 180-200°F for 1-to-3 minutes followed by a clear water rinse and air drying.

7.2.2 Cleaning

The lead pick-up from drop hammer operations was removed from the titanium alloy parts by immersion in a concentrated nitric acid or a 50 per cent (by weight) nitric acid solution in water for a period of time not exceeding 15 minutes. The titanium alloy was attacked a negligible amount by the acid solution when immersed for 15 minutes.

The removal of scale or discoloration formed at temperatures up to 1000°F were readily removed by immersion, at room temperature, in a solution of 8 per cent by weight nitric acid, 2 per cent by weight hydrofluoric acid and the balance water. The immersion time was held as short as possible, due to the rapid material loss and never exceeded a maximum of two minutes.

7.2.3 Surface Finishes

Surface finishes were treated, in general, the same as for stainless steel. The following is an excerpt from the finish specification for the titanium alloy pod project.

"Parts made from titanium alloy shall be insulated from magnesium and aluminum alloys. An acceptable insulation is two coats of zinc chromate primer, MIL-P-6889A, Type I, applied to the faying surface of titanium alloy in conjunction with the normally required paint coatings on the aluminum and magnesium. The primer coatings on the titanium shall extend at least one-half inch outside the faying edge on interior surfaces and up to the faying edge on exterior surfaces."

SECTION 8

QUALITY CONTROL PROCEDURES

SECTION VIII

QUALITY CONTROL PROCEDURES

8.1 Dimensional Control

When an order for the production of parts was ready for release to the shop area, the material having the acceptable characteristics for the operations to be performed was removed from stock. The pertinent information, such as actual gauge, vendor heat number, and sheet number was entered upon the production order. The material sheet was then forwarded for reduction to the required blank sizes.

Each forming operation which could result in a gauge loss, required an additional inspection operation. Parts showing a loss in excess of 10 per cent of the required gauge were rejected for material review board disposition.

After completing the final fabrication operations and inspections, acceptable parts were forwarded for cleaning operations. There, the parts were vapor degreased and then cleaned by lightly etching in acid bath cleaning solution for lead pickup and heat scale removal. Due to the etching action of the acid bath, considerable gauge loss was experienced during the cleaning operations. As a result the parts were again inspected for gauge loss and parts 10 per cent under the required gauge were rejected.

8.2 Nondestructive Testing

Following the cleaning and the subsequent inspection operation the parts were forwarded for a penetrant inspection. The parts were immersed in a fluorescent solution for 30 minutes, then removed and wiped dry. The parts were then exposed in a darkened room to a fluorescent light beam. Any crack, flaws or other minor ruptures were revealed. Such defects generally were not visible to normal visual inspection. Parts which showed such defects were rejected for material review board action.

8.3 Recognition of Material Defects

Titanium alloys, as were available for this project, had various defects which usually are not present in other aircraft materials.

One of the most serious defects was brittleness and poor elongation. Such defects were the prime causes for material loss during forming of sheet metal parts due to cracking and severe stress hardening. Poor elongation and brittleness could be determined by laboratory tests. This type of defect was usually confined to an individual sheet and when such was determined the sheet was segregated and released for production of parts requiring little or no forming. If this condition was too severe, the material was rejected and not used on the project.

Laps, laminations, and flaws were present in the available titanium alloy materials. Such conditions were not always visible until after forming or machining operations were begun. In sheet metal, such defects usually caused ruptures and a substantial loss of material.

Over-gauge material caused considerable trouble during forming operations, particularly on steel form dies. Due to the close draw clearance required in constructing good form dies, this over-gauge material caused binding and increased the galling tendency.

Much of the sheet stock received showed a poor surface finish. While no material structural quality was discernable because of this condition, it did increase friction and galling during forming.

8.4 Reclamation of Rejects

Because of the extreme shortage and high cost of titanium alloys, no material was rejected that could be utilized.

Every effort was made by collaboration between inspection, engineering, tooling and shop personnel to use the available material.

Material which developed a defect after forming or machining operations had started was rejected. It was then reviewed by a material review board consisting of engineering, inspection, and laboratory personnel. If it were possible to utilize the defective material in some other application, then the material was dispositioned in this manner.

Sheet material that had visible surface defects, was rejected and dispositioned to remove the defective area.

SECTION 9

STATIC TEST PROGRAM

SECTION IX

STATIC TEST PROGRAM

9.1 Intent

At the outset of the titanium alloy jet pod development project, it was intended that certain portions of the pods would be fabricated from titanium alloy and that three pods would be rebuilt. After a more complete investigation and a better understanding of the information to be gained from the static testing of a complete pod, Convair proposed an alternate program.

It was felt that static testing of titanium alloy parts, manufactured for this project, as details and/or assemblies rather than testing a complete pod would yield better engineering information such as:

1. Obtain ultimate strength of parts.
2. Obtain strength of parts at correct operating temperature.
3. Provide a comparison between the titanium alloy parts and identical parts fabricated from aluminum and steel.
4. Obtain basic structural data for tension field web sections, bolts, columns, and plate stringer combinations.

9.2 Scope

The static test program of testing structural elements was divided into two phases, with WADC conducting the actual tests.

"A" Test Program

Obtain ultimate and fatigue strengths at room temperature for the titanium alloy parts that are outside the heated area of the pod, i.e., the Front Spar Web, Rear Spar Side Brace, and the Rear Spar Terminals. (Reference Figures 32, 33, and 34, pages 107, 108, and 109)

"B" Test Program

Obtain ultimate and fatigue strengths at room temperature plus short time ultimate strength, creep-fatigue strength, and creep deformation at 300°F and 600°F for structural parts within the heated area of the pod. These parts to be made from aluminum, titanium alloy, and steel. The parts are the Rear Engine Support Beam Forging and the Rear Engine Support Strut Forging.

In addition, to obtain similar data for tension field web sections, bolts, and columns composed of angle sections, barrel tube sections and two plate stringer combinations. (Reference Figure 35, page 110)

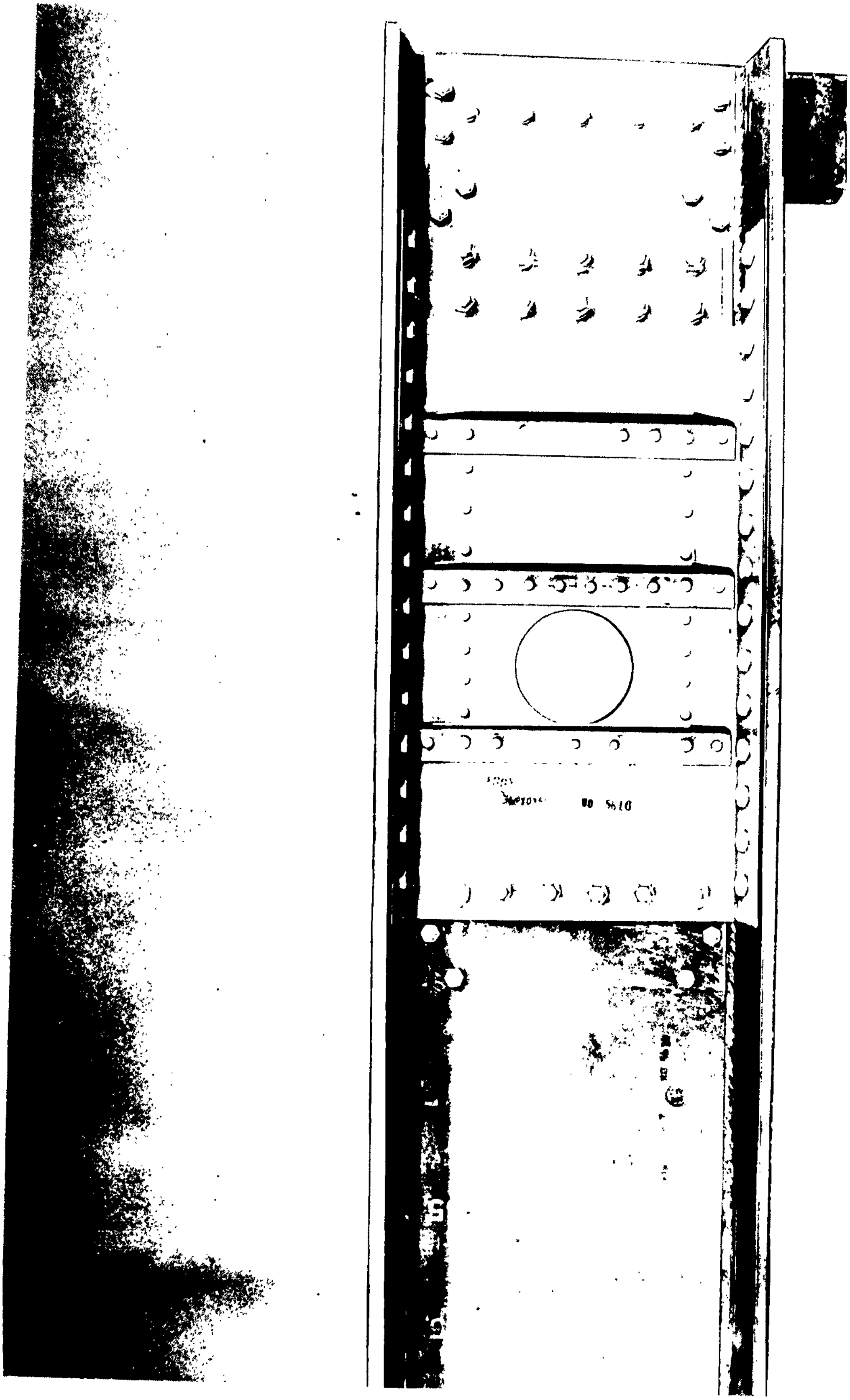


FIGURE 32
SHOWN HERE IS THE TEST JIG FOR THE FRONT SPAR WEB WITH A TEST PART INSTALLED.

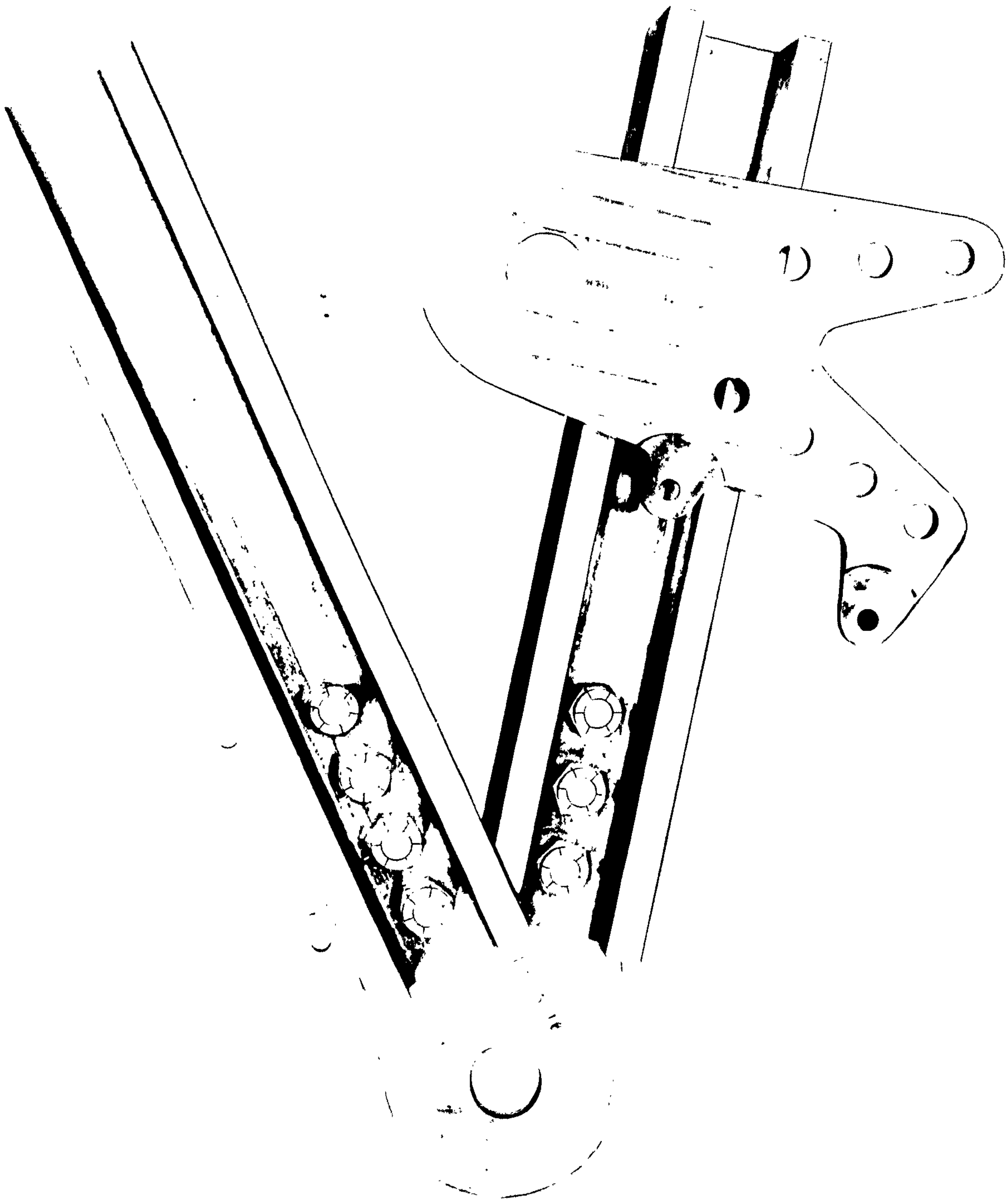


FIGURE 33

REAR SPAR TERMINAL FITTINGS AND TEST JIG FABRICATED FOR ULTIMATE STRENGTH

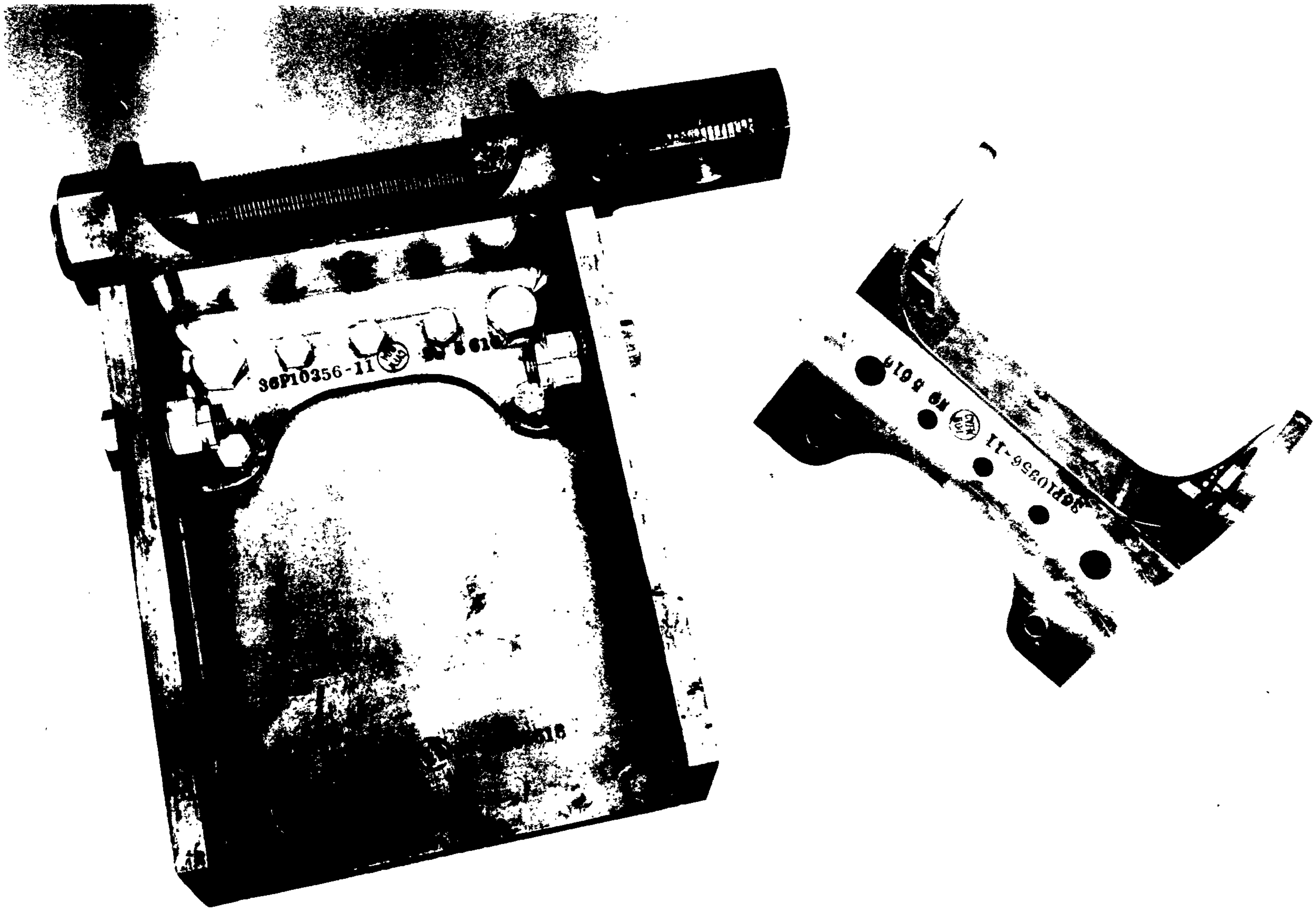


FIGURE 34

SHOWN ABOVE ARE TWO TITANIUM ALLOY FORGINGS (REAR SPAR SIDE BRACE) WITH THEIR TEST JIG FOR STATIC TESTING.

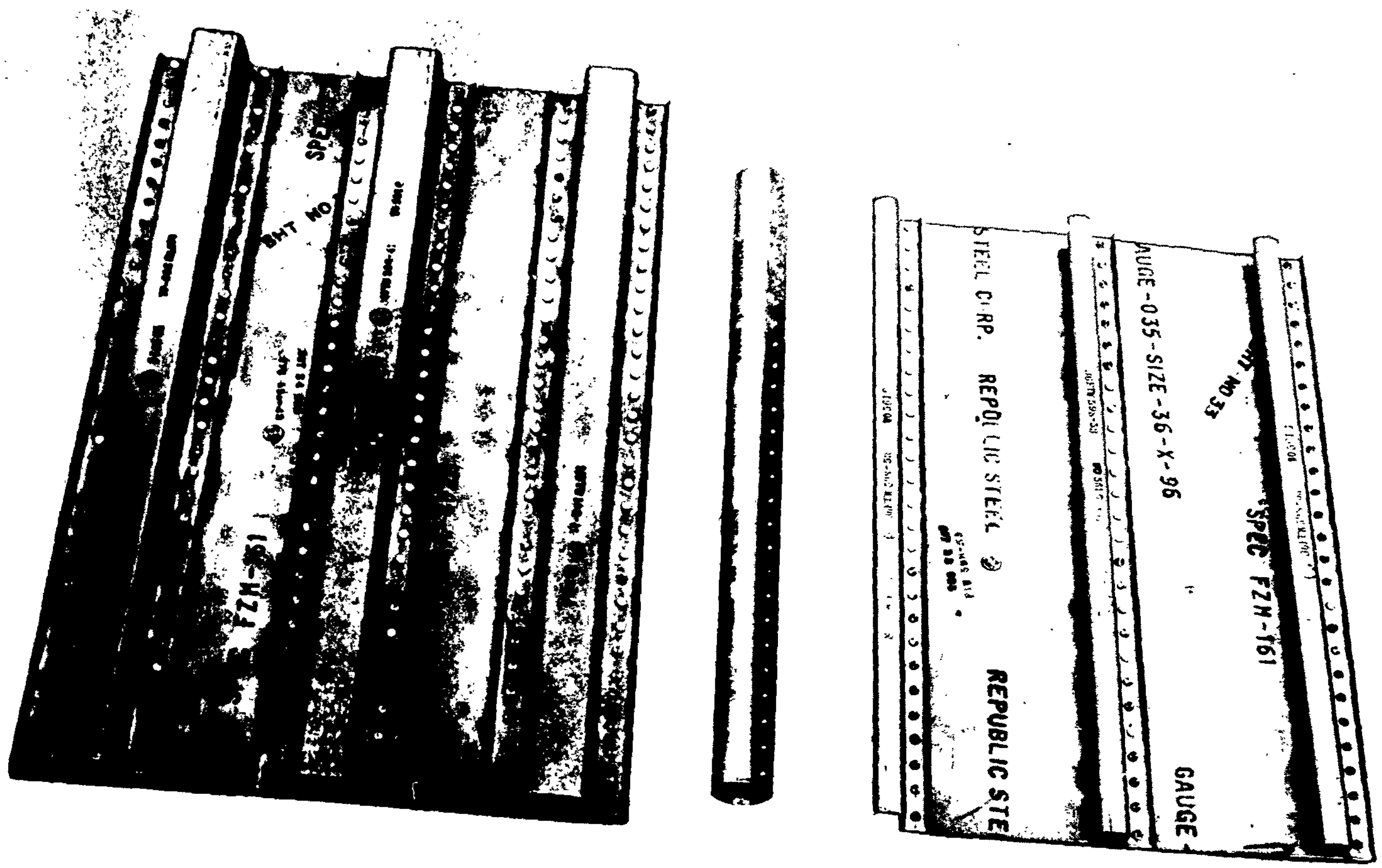


FIGURE 35

THE ABOVE PANELS WERE STATIC TESTED AS GROUND FLAT-ENDED COLUMNS TO OBTAIN CRIPPLING VALUES AND PLATE-STRINGER COMBINATION ALLOWABLES.

A total of 20 titanium alloy forgings, 18 steel forgings and 12 aluminum forgings were supplied to be tested.

In addition there were 39 titanium alloy, and 20 aluminum sheet metal assemblies fabricated and furnished for tests.

The titanium alloy bolts were procured from Reed and Prince Manufacturing Company and were made from RC-130B with hot, upset heads and rolled threads. (Reference Figures 36 and 37, pages 112, and 113)

9.3 Results

The results of the static test program as conducted at Headquarters, WADC, are taken from WADC Technical Notes WCLS-54-54 and WCLS-55-17. Details and photographs of the tests not included herein may be obtained from these reports.

From WCLS 54-54

Structural tests were conducted on elements of the B-36 engine pod for the purpose of proving certain parts composed of titanium to be structurally suitable for flight test, and to provide data for comparison purposes between titanium, aluminum, and steel components of the pod. Structural tests were also conducted on miscellaneous parts (bolts, tension field beams, columns, and plate stringer combinations composed of steel, titanium, and aluminum)

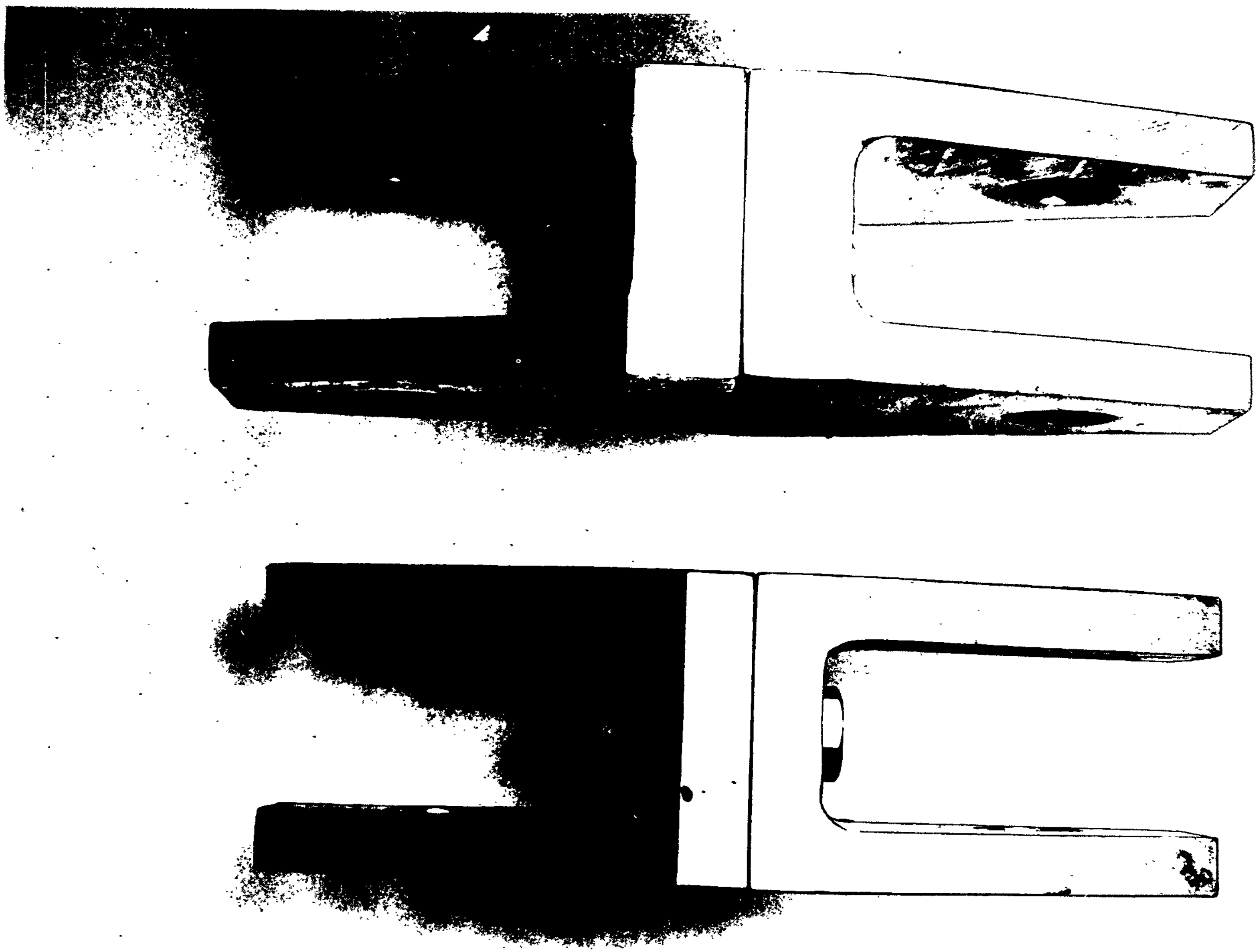


FIGURE 36

THE ABOVE JIGS WERE USED FOR TITANIUM ALLOY BOLT TESTS. THERE WERE NO TITANIUM BOLTS USED IN THE FLIGHT TEST PODS.

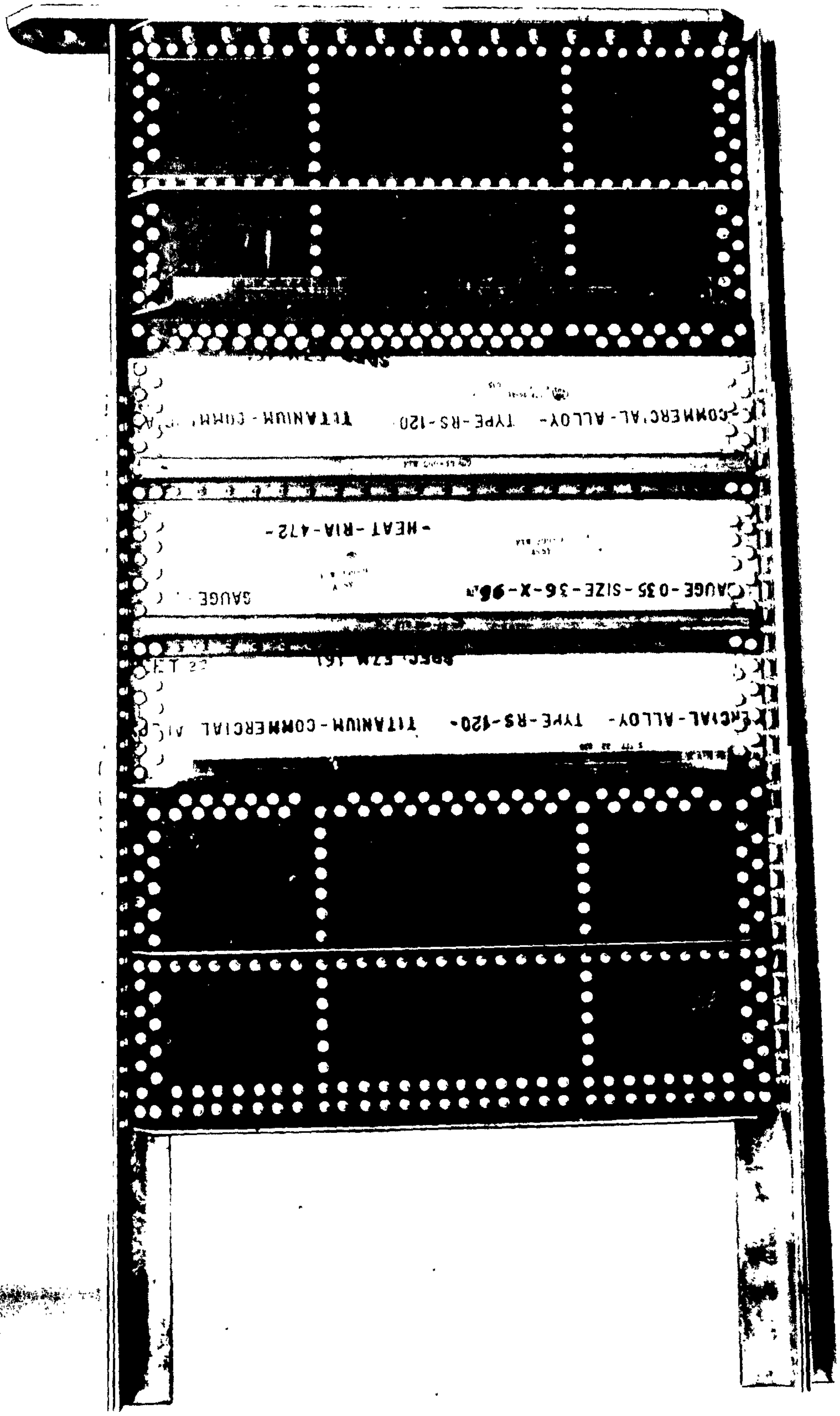


FIGURE 37

THE TEST JIG SHOWN ABOVE WAS ONE OF THREE FABRICATED FOR STATIC TESTING OF TENSION FIELD BEAM WEBS AND STIFFENERS. A TITANIUM ALLOY TEST PANEL IS SHOWN INSTALLED.

CVAC P/N 36P 10356-9; rear engine support beam, CVAC P/N 36P 10353; and strut fitting rear engine support, CVAC P/N 36P 10354, withstood at least 100 percent static ultimate load for the design conditions specified in Convair Report No. FZS-36-399.

Results of the room temperature fatigue tests on the titanium elements of the engine pod, as shown in Table IV, indicate that only the rear spar side brace exhibited acceptable fatigue properties. The upper front spar strut web at 1.44×10^6 cycles and the rear engine support beam at 2.94×10^4 cycles should be considered as exhibiting undesirable fatigue tendencies. It is recognized that the fatigue cycling load level used in testing the upper front spar strut web is high when compared to the design load, and that a substantial increase in fatigue life might be realized through reduction in the load level. However, it is pointed out that detail design of the web is such that poor fatigue properties can be expected with cracks initiating in the bend radii.

The TI 150 forgings, testing under this program, are decidedly inferior to alloys which have subsequently been developed. Hydrogen embrittlement has been found to seriously effect the strength properties of this alloy in other than short time loading applications.

Recommendations

In view of the comment in the above paragraph, it is recommended that extreme caution be exercised in utilizing parts composed of TI 150A alloy in applications where failure of the parts would jeopardize personnel or equipment.

If the upper front spar strut web, CVAC P/N 36P 10355, is to be used in its present configuration, it is recommended that additional fatigue tests using a more realistic fatigue cycling load level, be conducted prior to approval.

No recommendations are made pertaining to the bolts, tension field beams, columns, or plate stringer combinations tested, since the test data is for informational purposes only. It is noted, however, that improved strength characteristics of titanium bolts may be obtained by rolling rather than cutting the threads.

From WCLS 55-17

Stress rupture tests were conducted on the rear engine support strut fitting, CVAC P/N 36P 10354, for the purpose of determining the characteristics of the part under sustained loadings. (These data are not included in this report but can be obtained from WCLS 55-17). Fatigue tests for the purpose of obtaining allowables and data pertinent to possible subsequent supersonic designs. The tests were conducted at Headquarters, Wright Air Development Center, Wright Patterson Air Force Base, Ohio.

Fatigue tests at room temperature were conducted on the engine pod components as indicated in Table IV of this report (due to the limited load capacity of the fatigue testing equipment available, fatigue tests of the rear spar terminal, CVAC P/N 36P 10356-11, and the rear engine support fitting CVAC P/N 36P 10354, were not accomplished).

Static tests for the purpose of obtaining data pertaining to bolts, tension field web sections, and columns composed of barrel tube sections, plate stringer combinations, and angle sections, were conducted as indicated in Table V.

Fatigue tests at room temperature on steel, titanium, and aluminum bolts, and tension field beams for the purpose of obtaining comparative data were conducted as indicated in Table VI of this report.

Conclusions

As indicated in Table III, the titanium engine pod elements, Upper front spar strut web, CVAC P/N 36P 10355; rear spar side brace, CVAC P/N 36P 10356-11; rear spar terminal plate, on miscellaneous bolts were accomplished in order to complete the program.

Based on the limited data of the tests (Tables IV and VII) it is noted that the reduction of the fatigue load level from 0-5000 pounds to 0-40 percent design ultimate (3991 pounds) increased the fatigue life of the steel fittings to the theoretical infinite value. Comparable decreases in the load level for the aluminum and titanium rear engine support beams resulted in only negligible differences in the fatigue life noted, the titanium showing minor improvement.

TABLE III

Test No	Part Name &/or Number	Material	Rockwell	Design Load Number	Temperature	% Ultimate Load Supported		Date
1	36P 10355	Titanium		4442	Room	100	(1)	25 Aug. 53
2a	36P 10356-11	Titanium		6084	Room	1173	(1)	17 Sept 53
2b	36P 10356-11	Titanium		6084	Room	1345		2 Dec. 53
3	36P 10356-9	Titanium		112,806	Room	100	(1)	8 Oct. 53
4	36P 10356-9	Titanium		94,297	Room	123		14 Oct. 53
5a	36P 10353	Steel		9977	Room	100	(1)	Dec. 53
5b	36P 10353	Steel		9977	Room	253	(1)	Jan. 54
6	36P 10353	Steel		9977	300°F	(2)		Jan. 54
7	36P 10353	Steel		9977	600°F	100	(1)	Jan. 54
8	36P 10353	Aluminum		9977	Room	112		Dec. 53
9	36P 10353	Aluminum		9977	300°F	101		6 Jan. 54
10	36P 10353	Titanium		9977	Room	112		Jan. 54
11	36P 10353	Titanium		9977	300°F	171		Jan. 54
12	36P 10353	Titanium		9977	600°F	186		6 Jan. 54
13	36P 10354	Steel	C-34	P_H=10790	Room	260	(1)	16 Feb. 54
				P_V=9977		260	(1)	
14a	36P 10354	Steel	C-37	P_H=10790	300°F	230	(1)	17 Feb. 54
				P_V=9977		230	(1)	
14b	36P 10354	Steel	C-37	P_H=10790	300°F	210	(1)	17 Feb. 54
				P_V=9977	300°F	210	(1)	
15	36P 10354	Steel	C-35	P_H=10790	600°F	235	(1)	12 Feb. 54
				P_V=9977		235		
16	36P 10354	Aluminum	B-80	P_H=10790	Room	110	(1)	8 Feb. 54
				P_V=9977		108		
17	36P 10354	Aluminum	B-79	P_H=10790	300°F	100	(1)	9 Feb. 54
				P_V=9977		95		
18	36P 10354	Titanium	C-30	P_H=10790	Room	225	(1)	5 Feb. 54
				P_V=9977		225	(1)	
19	36P 10354	Titanium	C-30	P_H=10790	300°F	175	(1)	11 Feb. 54
				P_V=9977		175	(1)	
20	36P 10354	Titanium	C-30	P_H=10790	600°F	145	(1)	10 Feb. 54
				P_V=9977		145		

(1) Without Failure

TABLE IV

Test No.	Part Name &/or Number	Material	Design Load	Ultimate Strength	Load Level	Number of Cycles	Date
1	36P 10356-11	Titanium	6084		0-5000	10^7 (1)	4-27 Nov. 53
2	36P 10355	Titanium	4442		0-4000	2.5×10^6	5-14 Jan. 54
3	36P 10355	Titanium	4442		0-4000	1.44×10^6	18-20 Jan. 54
4	36P 10353	Steel	9977		0-5000	1.35×10^5	28 Jan. 54
5	36P 10353	Steel	9977		0-5000	1.53×10^5	29 Jan. 54
6	36P 10353	Aluminum	9977	11,210	0-4484	2.91×10^4	27 Jan. 54
7	36P 10353	Aluminum	9977		0-4484	4.35×10^4	27 Jan. 54
8	36P 10353	Titanium	9977	12,290	0-4916	2.94×10^4	27 Jan. 54
9	36P 10353	Titanium	9977		0-4916	3.17×10^4	27 Jan. 54

(1) Without Failure

TABLE V
STATIC TESTS

Test No	Part Name &/or Number	Material	Rockwell	Design Load	Temperature	Load Supported	Date
1	AN-4 Bolt	Steel	C-23	4080	Room	5655	Jul. 53
2	AN-4 Bolt	Steel	C-19	4080	Room	5120	Jul. 53
3	AN-4 Bolt	Steel	C-26	4080	300°F	5222	10 Aug. 53
4	AN-4 Bolt	Steel	C-23	4080	300°F	4128	11 Aug. 53
5	AN-4 Bolt	Steel	C-28	4080	600°F	5470	11 Aug. 53
6	AN-4 Bolt	Steel	C-29	4080	600°F	5570	11 Aug. 53
7	AN-4 Bolt	Aluminum	B-78	2030	Room	2705	Jul. 53
8	AN-4 Bolt	Aluminum	B-75	2030	300°F	2278	11 Aug. 53
9	AN-4 Bolt	Titanium	C-36		Room	5690	Jul. 53
10	AN-4 Bolt	Titanium	C-37		Room	5640	Jul. 53
11	AN-4 Bolt	Titanium	C-36		300°F	5371	11 Aug. 53
12	AN-4 Bolt	Titanium	C-36		300°F	5222	11 Aug. 53
13	AN-4 Bolt	Titanium	C-37		600°F	4923	11 Aug. 53
14	AN-4 Bolt	Titanium	C-36		600°F	4774	11 Aug. 53
15	AN-8 Bolt	Steel	C-27	18,500	Room	26,450	Jul. 53
16	AN-8 Bolt	Steel	C-22	18,500	Room	24,100	Jul. 53
17	AN-8 Bolt	Steel	C-26	18,500	300°F	21,684	7 Aug. 53
18	AN-8 Bolt	Steel	C-27	18,500	300°F	21,859	7 Aug. 53
19	AN-8 Bolt	Steel	C-27	18,500	300°F	22,733	10 Aug. 53
20	AN-8 Bolt	Steel	C-27	18,500	300°F	20,373	10 Aug. 53
21	AN-8 Bolt	Aluminum	B-69	9,180	Room	10,400	Jul. 53
22	AN-8 Bolt	Aluminum	B-69	9,180	300°F	9,410	10 Aug. 53
23	AN-8 Bolt	Titanium	C-39		Room	17,450	Jul. 53
24	AN-8 Bolt	Titanium	C-34		Room	21,600	Jul. 53
25	AN-8 Bolt	Titanium	C-34		300°F	21,159	7 Aug. 53
26	AN-8 Bolt	Titanium	C-35		300°F	21,859	10 Aug. 53
27	AN-8 Bolt	Titanium	C-34		600°F	18,361	10 Aug. 53
28	AN-8 Bolt	Titanium	C-35		600°F	19,236	10 Aug. 53
29	36FTW 598-11	Steel			Room	12,800 (1)	12 Feb. 54
30	36FTW 598-11	Steel			300°F	12,278	13 Apr. 54
31	36FTW 598-11	Steel			600°F	11,946	12 Apr. 54
32	36FTW 598-7	Aluminum			Room	7260 (1)	12 Feb. 54
33	36FTW 598-7	Aluminum			300°F	6968	13 Apr. 54
34	36FTW 598-9	Titanium			Room	18,080 (1)	12 Feb. 54

TABLE V (Cont'd)
STATIC TESTS

Test No	Part Name &/or Number	Material	Rockwell	Design Load	Temperature	Load Supported	Date
35	36FTW 598-9	Titanium			300°F	12,971	13 Apr. 54
36	36FTW 598-9	Titanium			600°F	9,955	12 Apr. 54
37	36FTW 598-23	Steel			Room	49,940	6 Apr. 54
38	36FTW 598-23	Steel			300°F	49,443	6 Apr. 54
39	36FTW 598-23	Steel			600°F	38,492	9 Apr. 54
40	36FTW 598-19	Aluminum			Room	22,564	6 Apr. 54
41	36FTW 598-19	Aluminum			300°F	20,573	14 Apr. 54
42	36FTW 598-21	Titanium			Room	37,165	6 Apr. 54
43	35FTW 598-21	Titanium			300°F	34,510	14 Apr. 54
44	36FTW 598-21	Titanium			600°F	31,856	2 Apr. 54
45	36FTW 598-17	Steel			Room	112,822	16 Apr. 54
46	36FTW 598-17	Steel			300°F	102,204	19 Apr. 54
47	36FTW 598-17	Steel			600°F	103,531	16 Apr. 54
48	36FTW 598-13	Aluminum			Room	49,775	16 Apr. 54
49	36FTW 598-13	Aluminum			300°F	46,456	19 Apr. 54
50	36FTW 598-15	Titanium			Room	85,612	16 Apr. 54
51	36FTW 598-15	Titanium			300°F	65,702	20 Apr. 54
52	36FTW 598-15	Titanium			600°F	62,384	19 Apr. 54
53	36FTW 299-7	Aluminum		36,000	Room	110% (2)	12 Mar. 54
54	36FTW 299-7	Aluminum		36,000	300°F	90% (2)	25 Mar. 54
55	36FTW 299-9	Titanium		36,000	Room	110% (2)	26 Feb. 54
56	36FTW 299-9	Titanium		36,000	300°F	90% (2)	23 Mar. 54
57	36FTW 299-9	Titanium		36,000	600°F	80% (2)	16 Mar. 54
58	36FTW 299-11	Steel		36,000	Room	90% (2)	26 Mar. 54
59	36FTW 299-11	Steel		36,000	300°F	90% (2)	24 Mar. 54
60	36FTW 299-11	Steel		36,000	600°F	100%	18 Mar. 54
61	36FTW 592-25	Aluminum			Room	3940	21 Apr. 54
62	36FTW 598-25	Aluminum			300°F	3698	28 May 54
63	36FTW 598-27	Titanium			Room	6800	21 Apr. 54
64	36FTW 598-27	Titanium			300°F	6734	28 May 54
65	36FTW 598-27	Titanium			600°F	5134	27 May 54
66	36FTW 598-29	Steel			Room	9460	21 Apr. 54
67	36FTW 598-29	Steel			300°F	9936	28 May 54
68	36FTW 598-29	Steel			600°F	8114	27 May 54

(1) One End Fixed, One End Pinned, All Others Both Ends Fixed
(2) Without Failure

TABLE VI

Test No	Part Name &/or Number	Material	Rockwall	Design Load	Average Ult. Strength	Load Level	Number of Cycles		Date
1	AN-4 Bolt	Steel		4080	5388	0-2155		(2)	
2	AN-4 Bolt	Steel		4080	5388	0-2155		(2)	
3	AN-4 Bolt	Aluminum		2030	2705	0-1352		(2)	
4	AN-4 Bolt	Aluminum		2030	2705	0-1352		(2)	
5	AN-4 Bolt	Aluminum		2030	2705	0-812		(2)	
6	AN-4 Bolt	Aluminum		2030	2705	0-812		(2)	
7	AN-4 Bolt	Titanium	C-33		5665	0-2266	5.06×10^5		16 Mar-17 Mar 54
8	AN-4 Bolt	Titanium	C-35		5665	0-2266		(2)	
9	AN-8 Bolt	Steel	C-27	18,500	25,275	0-10,110	10^7	(1)	3 Mar-13 Jul 54
10	AN-8 Bolt	Steel	C-26	18,500	25,275	0-10,110		(2)	
11	AN-8 Bolt	Aluminum		9180	10,400	0-5200	3.1×10^5		4 Feb 54
12	AN-8 Bolt	Aluminum	B-68	9180	10,400	0-5200	3.2×10^5		4 Feb 54
13	AN-8 Bolt	Aluminum	B-69	9180	10,400	0-3120	2.0×10^6		5 Feb-9 Feb 54
14	AN-8 Bolt	Aluminum	B-71	9180	10,400	0-3120	10^7	(1)	9 Feb-3 Mar 54
15	AN-8 Bolt	Titanium	C-34		19,525	0-7810	2.68×10^4		12 Mar 54
16	AN-8 Bolt	Titanium	C-35		19,525	0-7810	3.0×10^4		12 Mar 54
17	36FTW 299-11	Steel		36,000		0-14000	3.04×10^5		16 Apr-19 May 54
18	36FTW 299-7	Aluminum		36,000		0-14000	3.14×10^5		21 May- 2 Jun 54
19	36FTW 299-9	Titanium		36,000		0-14000	10^5		9 Apr-12 Apr 54

TABLE VII

Test No	Part Name &/or Number	Material	Design Load	Ultimate Strength	Load Level	Number of Cycles	Date
10	36P 10353	Titanium	9977	12,290	0-3991	7×10^4	5 Aug. 54
							6 Aug. 54
11	36P 10353	Aluminum	9977	11,210	0-3991	6.8×10^4	6 Aug. 54
12	36P 10353	Steel	9977		0-3991	10^7(1)	6 Aug. 54
							28 Dec. 54
13	36P 10353	Titanium	9977	12,290	0-3991	5×10^4	28 Dec. 54
							29 Dec. 54
14	36P 10353	Aluminum	9977	11,210	0-3991	2.9×10^4	29 Dec. 54

(1) Without Failure

Note: This Table is a continuation of Table IV

TABLE VIII

Test No.	Part Name &/or	Material	Rockwell	Design Ultimate	Average Ultimate Strength	Load Level	Number of Cycles	Dates
1	AN-4 Bolt	Steel	C-28	4080	5388	0-2155	10^7 (1)	14 Jan. 55- 9 Feb. 55
2	AN-4 Bolt	Steel	C-27	4080	5388	0-2155	10^7 (1)	10 Feb. 55 15 Feb. 55
3	AN-4 Bolt	Aluminum	B-73	2030	2705	0-1352	10^7 (1)	16 Feb. 55 21 Feb. 55
4	AN-4 Bolt	Aluminum	B-73	2030	2705	0-1352	6.9×10^5	21 Feb. 55
5	AN-4 Bolt	Aluminum	B-74	2030	2705	0-812	10^7 (1)	24 Feb. 55 1 Mar. 55
6	AN-4 Bolt	Aluminum		2030	2705	0-812	10^7 (1)	1 Mar. 55 7 Mar. 55
8	AN-4 Bolt	Titanium	C-35		5665	0-2266	10^7 (1)	18 Mar. 54 5 Jan. 55
10	AN-8 Bolt	Steel	C-26	18,500	25,275	0-10,110	4×10^6 (1)	13 July 54- 22 July 54
20	AN-4 Bolt	Titanium	C-34		5665	0-2266	10^7 (1)	5 Jan. 55- 14 Jan. 55
21	AN-4 Bolt	Aluminum	B-73	2030	2705	0-1352	1.03×10^6	21 Feb. 55- 23 Feb. 55

(1) Without Failure

SECTION 10

FLIGHT TEST PROGRAM

SECTION X

FLIGHT TEST PROGRAM

10.1 <u>Summary</u>

Upon completion of fabrication of the two flight test pods, J47 jet engines were installed and then the pods were hung on B-36D Airplane No. 51 (USAF Serial No. 44-92054) and flight tested from 11 March 1954 to 28 August 1954.

During this test period a total flight time of 183 hours was accumulated on 33 flights of the airplane. The jet engines were operated an average of 80 hours of which 67 hours were during flight.

10.2 <u>Discussion</u>

Since the purpose of the flight test program was to determine the serviceability of the titanium alloy jet pod nacelle components when subjected to actual service conditions, no instrumentation was installed. After each flight the titanium parts were visually inspected to determine if any failures had occurred or were suspected to occur.

Two minor failures were found after approximately 130 flight hours. These occurred in small angle stiffeners of the right hand pod box beam assembly. In each case, a crack started from the edge of the stiffener and terminated in a bolt hole. Because the stiffeners had to pick-up an existing bolt pattern, each of the holes had short edge distance.

It was determined that these cracks did not affect the structural integrity of the pods, so the flight testing was continued.

10.3 Results

Upon completion of the flight test program, the pods were removed from the airplane and partially disassembled, and all parts were again visually inspected. In addition to the visual inspection all parts were subjected to a dye penetrant inspection and no cracks or failures were found.

The titanium alloy components were still entirely serviceable after accumulating 183 hours of flight time.